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Jatropha Sector Review

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Introduction

The success of humanity in taking control of Earth has involved a series of partnerships with plants of outstanding utility. Our relationship with these crops is a constant strand in the history of our species and a defining expression of our presence on the planet. Consider that just four crops: wheat, corn, rice and soya cover more than 5% of the World's land area. This compares with 2.7% for cities and 12% for the remaining rainforests. These are 'conqueror crops'. *Jatropha curcas*, traditionally an undomesticated hedging plant with secondary utility as a source of oil, came to prominence when it was proposed as a feedstock for biofuel during an earlier era when crude oil was trading over $70 bbl. Research into the plant's properties reveals that it has far greater utility than just as a source of energy. In this report we detail how Jatropha derived products have the scope to address an annual global sales opportunity of more than $120 billion in a variety of high value industrial applications. Addressing at least 8 classes of industrial applications, Jatropha derived components, have in a number of cases, superior technical functionality to competitor plant products, hinting at the crop's potential to increase its importance for mankind. However, unless there is a credible prospect of scaled, economic, upstream supply of Jatropha commodities, these opportunities will be lost to proven commercial crops, such as soya and oil palm. A group of industrial investors and the crop science entities they are supporting (including names such as JOil in Singapore and Resolute Genetics in San Diego), are racing to put Jatropha into contention, to address the opportunities briefly detailed herein.

Industrial opportunities for Jatropha

Industrial Product Sector	Global $m Value (2015)	Jatropha Component	Why Jatropha	Opportunity	Comment
Polyurethane	50,000	Jatropha Oil from Kernel	High hydroxyl number polyols	Consumer pressure for 'green' products; pressure on industry to reduce GHG emissions	Technical superiority to other volume vegetable oils provides Jatropha with an opportunity
Surfactants	30,000	Jatropha oil from Kernel	Wetting properties and antimicrobial action	Demand for bio-based products	Must compete with other vegetable oils which are well-established in market
Adhesives, Resins & Glues for Wood Products	17,000	Protein from Kernel Meal	Increased water resistance due to presence of glutelin proteins	Regulatory pressure to reduce or eliminate use of formaldehyde as base for wood adhesives since recognition as a carcinogenic and mutagenic agent	Technical superiority to other volume vegetable proteins provides Jatropha with an opportunity
Metal Working Fluids	10,000	Jatropha Oil from Kernel	Greater lubricity	Regulatory pressure to reduce environmental damage created by toxic waste from mineral oil based fluids and health risks to industrial workers from same	Must compete with other vegetable oils which are well-established in market
Carbon Fibre	10,000	Lignin from Jatropha seed coat	Jatropha lignin is homopolymeric	Homopolymeric plant lignins may offer cheaper precursor for carbon fibre than mineral oil based precursors	Technical superiority to other plant lignins provides Jatropha with an opportunity
Industrial Lubricants (Independent Manufacturers)	6,500	Jatropha Oil from Kernel	pour point, viscosity and thermal oxidative stability	Regulatory & consumer pressure for bio-based products	Must compete with other vegetable oils which are well-established in market
Biopesticide	445	Jatropha Oil from Kernel and Phorbol Esters	Effective against thrips, biodegradable	Growth in biopesticides	Considerable technical & regulatory hurdles to overcome
Dielectric Coolants	2,100	Jatropha Oil from Kernel	Viscosity close to diesel, high flash point, low pour point	Demand for bio-degradable products	Must compete with other vegetable oils which are well-established in market
Value of All Global Market Segments	**126,045**	**Multiple**	**Strong technical merits**	**Significant market opportunities for Jatropha fractions exhibiting technical superiority.**	**Requires volume production of Jatropha**

Source: Hardman Agribusiness

Research & Development Investment

Over the past decade Hardman Agribusiness (HAB) estimates that investment in the research and development of *Jatropha curcas* (Jatropha) as a commercially valuable species, has exceeded $160m, and may be closer to $200m. While the research and development budgets of the various crop science entities in the field, are not a matter of public record, various of the senior names in the sector have been clients of HAB over the years, and we have been able to gauge the quantum of their annual investment in the science of the crop. But other names, often small divisions or subsidiaries of major corporations, have been opaque to us, leaving only scope for estimation about their annual investments. $160m is a fair, but conservative estimate of the investments made by the companies and entities we know, $200m includes estimates for the parties for which we have been unable to sight investment values. In the context of a new agricultural species, not yet proven, this is a significant level of investment.

Jatropha is a species with significant and valuable agricultural attributes, it is hardy, fast growing, early to fruit, productive and diverse in its physiology; the development and breeding strategies to harness the crop's potential are also diverse and drawn from more than 40 years of aggregated scientific research. Some breeding strategies are based on shaping the adaptability of the plant to suit specific environments or cultivation models, while others are radical: think of Jatropha being grown as an annual crop in North America or Europe, at 30,000 plants per ha. Today growers can make choices based on a variety of characteristics including suitability for the intended cultivation site, disease & pest resistance, harvest period, oil yield, maturation period and toxicity levels – a remarkable progression from even 7 years ago when one start-up plantation development chose its wild sourced planting material on the basis of individual seed weight. In 2010, growers could expect not much more than 1.5 mt/ha of dry seeds at maturity (3-5 years), albeit that they were targeting achieving yields of 4.0 mt/ha. Just seven years later, 2.5 mt / ha in the first year of planting is not beyond reach using modern, early cropping commercial hybrids, in suitable agronomic environments.

For the crop science entities focused on the crop's evolution from wild species to commercial hybrid lines, the last ten years have thrown up considerable challenges, and not all of those entities have survived. Most have reduced their research budgets, some have withdrawn from the endeavour, but others have focused their activities on specific opportunities to achieve a return on their investments.

Disruptive Crude Oil

When Jatropha first came to prominence towards the end of the 20th Century and the early years of the 21st Century, it was misrepresented as a 'miracle plant' capable of producing economic volumes of high quality oil for the production of biodiesel, whilst growing in near desert conditions. For a tropical species, this was an impossible 'ask'. While the crop has provided considerable utility down the centuries for populations stretching from its source in Central America to Africa and Asia, providing lamp oil, hedging, medicinal and culinary use (in its non-toxic form), it was first brought to the attention of investors, as a biofuel feedstock. With excellent suitability for a variety of fuels including biodiesel and jet-fuel, the crop was promoted as a non-food source of biofuel. However, the economic case for Jatropha oil as feedstock, falls apart when crude mineral oil is trading below $500/mt equivalent ($70 bbl). During the period September 2005 to June 2014, crude oil traded between $60 bbl to $130 bbl, implying economic viability for Jatropha oil at a production cost of up to $700 mt. Since May 2015, the price of crude has remained below $70 bbl, demanding a reconsideration of the Jatropha business model.

Too Good to Burn

For exponents of the crop, this reconsideration is strongly welcomed: for the scientists most familiar with the qualities of Jatropha derived products, they are simply 'too good to burn'. In this report we briefly outline five high value industrial applications for Jatropha derived products, where the distinct qualities of the plant, lend themselves to the production of superior industrial formats within these five segments. For the significant industrial investors (many are globally important manufacturers) who have supported the progressive development of Jatropha by the crop science entities focused on it, validation of their support for the crop, would be strongly confirmed, if Jatropha derivatives were to become preferred components in almost any of these industrial applications.

The economic model for the production of Jatropha for any application, has yet to be proven. The biofuel feedstock model remains reasonably well-suited to many of the energy poor developing economies across the tropical and arid regions, but this in turn is dependent on the availability of low paid rural labour. Traditionally Jatropha has been viewed as a crop for production under an out-grower or smallholder model, and this model has logic, for countries with large pools of poor rural labourers. Yet, if higher value applications can be found for the crop, spanning the entire value chain, then even in poorer countries, Jatropha may have a useful, potentially important, economic role to play. We detail herein the opportunity for Jatropha oil to provide precursors for polyurethane, which in turn would be used to manufacture biodegradable flip-flops and sandals (the primary shoe category for some 3 billion people in the developing economies), all in the country of origin.

Any analysis of the economics of Jatropha under cultivation must begin by defining the setting for such cultivation. The once traditional vision of the crop for use in marginal or degraded lands in semi-arid environments, achieving yields of less than 1mt of dry seed per hectare, was one based on poverty alleviation in the most testing of conditions. Under favourable growing conditions, our assessment of the state of development of the crop suggests that yields of dry seed per ha may be achievable in a range of 2mt to 6mt, and possibly more under intensive management.

Production costs will look very different across this range of models and so too will revenues per ha. In the more difficult cultivation environments marked by poverty and poor logistics, lower revenue outcomes may potentially be offset by cheap labour, and possibly benefited by opportunities to produce biodiesel produced at source. In highly suitable cultivation environments, higher labour and operational costs will need to be offset by better values for Jatropha derived products. The traditional model of Jatropha oil for biodiesel and Jatropha meal for use in animal nutrition (once an approved, commercially scaled process became available for the detoxification process), has lost its conviction in the face of cheap crude oil and the rising volumes of soya beans produced annually: currently some 351 million metric tonnes (USDA). But the production of Jatropha for processing (of its fractions) into the precursors, or base components of adhesives, surfactants, metalworking fluids, polyurethane or biopesticides would provide the basis for new economic models, based not just on financial returns, but also on reductions in environmental impact and potentially, significantly improved outcomes for workers and consumers.

Wood Adhesives

Bio-based Alternatives for Formaldehyde Based Systems

Water Resistance

Across the wood products adhesives sector, it has been recognised that water resistance in many plant protein-based adhesives, is sub-standard. However, Jatropha based adhesives have increased water resistance, due to the presence of glutelin proteins, which are renowned for resistance to water. (The term glutelin is used for seed proteins that are insoluble in water but soluble in acidified or alkaline solutions).

This problem with water resistance, looks likely to prevent traditional bio-alternatives, such as soya-based adhesives from being a suitable technological substitute for systems based on formaldehyde. Soya flour based adhesives cannot be used in any other products than those classified as 'No-Added Formaldehyde' (NAF), and 'Ultra-Low Emitting Formaldehyde' (ULEF), which represent just 2% of the wood panel market.

Formaldehyde Emissions

Both during the manufacturing of traditional wood products and in use, formaldehyde can be released from the wood-based materials (Fraunhofer Institute for Wood Research, 2017). The formaldehyde-based resin manufacturing industry has been facing an increasing challenge since formaldehyde was classified as carcinogenic and mutagenic in the 6th adaptation to technical and scientific progress of the CLP (Classification, Labelling and Packaging) EU directive in June 2014. This classification has far-reaching and immediate consequences for a variety of business sectors. Within the EU, since 1st January 2016, formaldehyde has been classified as carcinogenic, having already been singled out for being toxic (skin contact, inhalation).

Formaldehyde is a key material for the chemical industry, serving as the source for many chemical compounds. The EU produces approximately 10 million tonnes per year and 47 million tonnes of formaldehyde are produced worldwide. A large proportion of synthesised formaldehyde is used in the production of glues and impregnating resins for wood-based materials. Adhesive resins are used in the manufacture of particle boards, plywood panels and chipboards, where the furniture industry is one of the main users.

Regulatory Environment US, Japan and European Union

The California Air Resources Board (CARB) and the USA has moved to tighten legislation controlling formaldehyde emissions from wood products (specifically from wood glues and adhesives), with specified allowable formaldehyde emissions levels. President Obama and the state of California, both advocates of large environmental regulation and climate change mitigation, led this regulation revolution, and even with President Trump seeming to slow the pace at which the final regulations are formalised, it will change the fundamentals of the wood industry.

On 26th April 2007, CARB approved measures to reduce formaldehyde emissions from composite wood products, including hardwood plywood, particleboard, medium density fibreboard, thin medium density fibreboard and finished goods made with composite wood products. This was the initial move away from traditional manufacturing.

However, a transformational moment for the industry occurred when CBS News aired an investigation, on 1st March 2015, into claims that US wood products distributor, Lumber Liquidators' Chinese-made laminate flooring contained dangerous levels of formaldehyde. As part of the investigation, more than 150 boxes of laminate flooring were tested in three certified labs. In all tests, the flooring failed to meet formaldehyde emission standards set by California state law, with some flooring testing almost twenty times over the permissible level. Following the initial investigation, further samples of flooring sold in Virginia, Florida, Texas, Illinois and New York were tested. Of the 31 boxes tested, only one was compliant with CARB emission standards – these are the same standards that are to be rolled out nationwide.

Within the European Union, E1 and E0 are the current formaldehyde emission standards. E1 emission standards are the oldest and most well–known; to meet E1 formaldehyde standards products must have less than 0.75 formaldehyde parts per million (ppm). E0 is an updated version of E1 with much more stringent standards requiring formaldehyde emissions to be equal to or less than 0.07ppm. Both the California Air Resource Board CARB Formaldehyde Emission Standards and the Japanese Emission Standards (JIS/JAS F****) are more stringent than their European equivalents.

This suggests that the potential market for bio-adhesives for the wood products sector, based on plant fractions, may be significantly greater in the US and Japanese markets, than in Europe under the current EU regulatory regime. According to the Timber Trade Federation based in London, in the short term there is likely to be a 'move away' from formaldehyde based technologies in Europe, but they are unlikely to be completely forced out of the market. The most stringent EU states are Austria, France and Germany. The European and UK Regulators, are more focused on the reduction of formaldehyde levels in adhesive products, rather than replacement of formaldehyde systems by bio-based alternatives.

Even though the European Union falls somewhat behind Japan and the USA on the progress of regulatory change, we suspect that it is only a matter of time before European manufacturers will face the same regulatory, and if not regulatory, consumer pressures to reduce and or replace formaldehyde based glues, resins and adhesives from wood products, given consumer interest in more environmentally conscious construction, whether residential or commercial.

Alternatives to Formaldehyde Based Systems

Market Value

Wood adhesives/resins/glues, have a global market valued at $17bn (2015, expected to rise to $24bn by 2021) and in 2014, the European wood-based panel industry consumed over 4 million tons of formaldehyde based glue to produce wood panels. The current (USA, Japan), or upcoming (EU) industry wide change, has led to considerable research into potential substitute products.

Chemical non-formaldehyde Alternatives

Emulsion Polymer Isocyanate (EPI) Adhesives are a current alternative, that do not contain formaldehyde but being a synthetic, toxic non-bio resin, the technology does incur environmental issues in using petroleum based products during production. EPI adhesives are dual-component systems: a water-based emulsion with an isocyanate hardener.

EPIs are chosen for a variety of reasons;

- High moisture and temperature resistance
- Durability but flexibility in curing
- Bonding performance to substrates such as wood, metal, plastics, etc.

Bio-resins

EU recommendations for the replacement of formaldehyde based systems are suggested and verified by the European Panel Federation (EPF). Once the EPF recognizes that there are suitable alternatives available, meeting the core criteria of adhesive strength, required viscosity and non-food origin, it is argued that more stringent formaldehyde regulation can be implemented, potentially leading to a complete ban on formaldehyde based systems.

The Forestry Commission stated in its 2007 report (Review of existing bio-resins and their applications) that 'bio-resins must be sustainable', including in respect of:

- Land use issues regarding competition for land with other needs: agriculture, conservation, building
- Being economic to produce
- Being connected to a regional supply chain
- Being non-toxic in production and use
- Being of 'equivalent' long term performance
- Producing no compromises at end of life.

The nature of these characteristics highlights the difficulty of producing an appropriate bio-based resin. Alternatives must deliver the same performance as mineral oil based systems, whilst providing better sustainability, and environmental performance.

Soya, A 'Stop Gap' Solution

Soya based products have gained initial market penetration, particularly in North America, with soya flour based adhesives representing the 'natural' substitute for formaldehyde based products. Soya based adhesives, manufactured from domestically produced soya beans also fulfil 'the grow America' principle. Leading suppliers into the North American market include Cargill and Solenis.

However, leading market actors have advised HAB that soya based resins are only a 'stop gap' solution, their usage based largely on traditional practice. The 2007 Forestry Commission Report (review of existing bio-resins and their applications) supported this interpretation "Soy-protein based wood adhesives have been used for centuries… since WW2 they have been largely replaced by petroleum based adhesives". The traditional soya based technologies, have been largely replaced in the market place by petrochemical based adhesive technologies, and in particular by formaldehyde based systems, due to the performance limitations of the soya based products, under humid conditions. Due to growing concerns about Volatile Organic Compounds (VOC) activity with formaldehyde based adhesive technologies, some manufacturers, (Solenis is an example), are now offering combinations of bio-based and petrochemical based systems for the wood products market. (eg; Soyad). Industry experts argue that for fully bio-based systems to succeed in this market, more advanced technologies are required.

Soyad™ adhesive technology is a patented, formaldehyde-free adhesive system from Solenis that is used to manufacture environmentally-friendly particleboard panels. Soyad adhesives are water-based systems formulated with natural soy flour and a proprietary cross-linking resin. When blended together the resin reacts with the protein in the soy flour to form a durable thermoset adhesive. Solenis advertises that the strength provided by Soyad adhesives is "*comparable to that of other no-added-formaldehyde (NAF) technologies and traditional formaldehyde-based adhesive systems*". Formaldehyde emissions from particleboard panels made with Soyad are claimed to be "*significantly below CARB Phase 2 emission standards and consistently below emission targets for panels made with low-emitting urea-formaldehyde (UF) resins*". Depending on the core adhesive used, particleboard manufacturers that use Soyad adhesives may be eligible for either a ULEF exemption or a NAF exemption from third-party certification requirements. Likewise, particleboard panels made with Soyad adhesives may meet European E0 and Japanese F**** formaldehyde emission standards.

Alternatives to Soya

Because the EPF recommends that bio-based products for the EU market should be derived from 'non-edible' sources, soya-based adhesives may meet resistance in gaining full market acceptance, notwithstanding that globally some 350 million mt of soya-beans are produced annually (USDA, 2017). In the event that Jatropha derived products can exceed the technical performance limits of soya-based products, the classification of Jatropha as an industrial feedstock, as opposed to a food chain crop, could work in its favour.

Further bio-resins that have achieved publicity in the wood adhesives market, have been based on

- Tannins & Lignins
- Cashew nut shell liquid
- Starch based
- Other vegetable oils such as rapeseed and sunflower.

'Bio-Based Adhesives and Evaluation for Wood Composites Application' written by Ferdosian et al. (2017) summarises the "*rapid growth in research and innovation of bio-based adhesives in the engineered wood product industry*" and "*reviews the recent research published… on the synthesis of bio-adhesives*".

Jatropha Protein

The Italian processing company Agroils SpA, has developed a Jatropha protein based Formaldehyde-free bio-glue, branded under the name JADE. The technology for JADE has been developed in collaboration with a number of manufacturers of plywood in Italy, including Panguaneta SpA and Vigolungo SpA. The Italian plywood industry is thought to consume around 20,000 mt of Formaldehyde resins annually.

Panguaneta and other names in the Italian sector began placing orders for JADE in August of 2017, which Agroils reports, are running at around 1 mt per month. Panguaneta has further undertaken to initiate the process of registering JADE with the Californian Air Resources Board (CARB) for use in Not-Added Formaldehyde (NAF) panels production. Vigolungo has also placed orders for JADE with Agroils, amounting now to 0.6 mt. Producing some 60,000 m3 of plywood annually, Vigolungo is one of the leading producers in Italy.

Agroils has been collaborating also with particleboard / MDF manufacturers including the Saviola Group which produces circa 1 million m3 of particleboard panels annually and approximately 200,000 mt of Formaldehyde based glue. The objective of the collaboration is to produce Formaldehyde-free particleboard. Agroils reports that laboratory testing was completed in September 2017. The company is optimistic that it will receive initial orders for its Jatropha based technology in the near future. The Italian producer Fantoni SpA, with plants in Serbia and Croatia, consumes some 150,000 mt of Formaldehyde based glues every year. Agroils has been supplying the manufacturer several MDF and particleboard samples (using Agroils Jatropha technologies) based on Fantoni fibres. The company advises that it has now delivered to Fantoni samples of particleboard panelling compliant with European industry standards. Agroils is now preparing for an industrial test.

Metal Working Fluids

In 2015 global sales of Metalworking fluids (MWFs) were a little under $10bn, and with increasing industrialisation across the developing economies, some forecasters are projecting CAGR of 4%-5% for the segment into the middle of the next decade.

Environmental & Worker Health Issues

Metalworking fluids (MWFs) are mainly used as lubricants and coolants in metal cutting and forming operations. There are growing concerns regarding the environmental impact of disposing of toxic waste from mineral oil based MWFs, and about their impact on the health of industrial workers. The discharge of non-biodegradable cutting fluids can widely affect the environment due to hazardous metal carry-off, reduction of nutrients in the soil, and oxygen depletion. These concerns have led to the introduction of stringent environmental regulations, and health & safety controls in the workplace. Confronted by the health and environmental risks from the use of synthetic MWFs, there has been mounting pressure from global energy authorities and environmental protection agencies, for the development of bio-based alternatives to the traditional cutting fluids technologies. Two million tons of synthetic lubricants are thought to be wasted in Europe each year, with traditional mineral cutting fluids posing significant environmental hazards throughout their life cycle, but specifically at end of life disposal (Clarens et al., 2008 – Comparison of life cycle emissions and energy consumption for environmentally adapted MWF systems).

According to Li et al (2003), 'Health Risks from Exposure to MWFs in Machinery and Grinding Operations', 70% of all occupational diseases amongst machine operators, were due to skin contact with synthetic cutting fluids. It is estimated that approximately 1 million workers are exposed to MWFs. Concerns about the health risk to these workers is creating a market opportunity for safer bio-alternative products. Health issues from exposure to MWFs, according to the Health and Safety Executive website, include:

- Skin irritation and dermatitis
- occupational asthma, bronchitis, irritation of the upper respiratory tract, breathing difficulties
- rarely, extrinsic allergic alveolitis (EAA), a serious lung disease.

The Italian process engineering company, Agroils Technologies SPA has been developing the technology for a Jatropha oil based MWF. The company reports that it is in discussions with two European MWFs manufacturers, and that tests conducted with its Jatropha technology, suggest that the Jatropha based product compares well with synthetic lubricants currently in use.

Plant Oil Based Alternatives

Since 2011, TOTAL Special Fluids (TSF), a major producer of hydrocarbon fluids for industry has been engaged in a research programme to develop bio-sourced products, using a range of Hydrogenated Vegetable Oil (HVO) sources including a mix of Palm Fatty Acid Distillate (PFAD) and Crude Palm Oil (CPO). Then in 2016 TSF introduced the BioLife range of bio-sourced, bio-degradable isoparaffin products. These products were tailored for targeted applications with a narrow boiling range and ultra-low aromatics, for worker comfort. TSF advertises that the BioLife range is suitable for a wide range of applications including: drilling fluids, heat transfer, lubricants, hydraulic and metal-working fluids.

Jatropha Oil MWFs

DAW-AEROCIT, the German manufacturer of industrial lubricants, has performed comparison studies on cutting fluids made from Jatropha oil and fluids made from mineral oil. The Jatropha based product was found to achieve comparable, and in some cases, a better lubricity. The trials suggested that Jatropha based systems, in operation in the metal working sector, could permit higher tool life and better work piece efficiency, compared to MWFs based on mineral oil. If Jatropha oil based products can be shown to give greater performance, coupled with an absence of health risk, and a low environmental impact, then there may be a significant market opportunity for such products within the MWFs sector. Agroils confirms that it has fulfilled a commercial order of Jatropha oil to Daw Aerocit. The Italian processor is in advanced talks also with Foundry Alfe Chem, another supplier of industrial lubricants, with the objective of commencing commercial supply.

MWFs

Across the globe, the growing rate of industrialization in the developing economies, has seen a rise in the use of MWFs. Dominant within this product/technology segment are new, modified, cost effective petroleum and synthetic chemical based cutting fluids. These products are extensively used in the “machining industries”. Based on functionality, MWFs may be removal fluids, treating fluids, forming fluids or protecting fluids. MWFs can be manufactured using diverse raw materials including petroleum distillates, plant oil and animal fat.

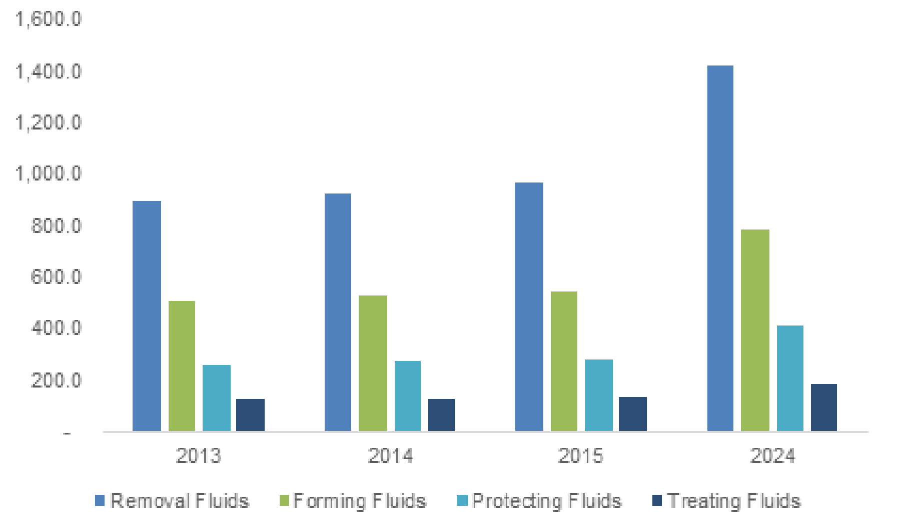
The Occupational Safety and Health Administration (OSHA), defines Metal Working Fluids (MWFs) as “neat oils or water-based fluids used during the machining and shaping of metals to provide lubrication and cooling. These fluids, reduce friction and heat whilst removing metal chips produced during the cutting process. The prevention of thermal damage to the product, and the minimization of wear to the machining equipment during manufacturing, are the critical aspects of their functionality. Metal working fluids can be classified as:

- Hardening MWF;
- Water miscible MWF;
- Non-Water miscible MWF;
- Corrosion protection MWF.

Global Metalworking Fluids Market

The MWFs market was estimated by the research agency Global Market Insights (https://www.gminsights.com/industry-analysis/metalworking-fluids-market) at more than US$ 9.85 billion in 2015 and was forecast to achieve a CAGR of 4.6% plus, by 2024.

U.S Metalworking Fluids Market size, by application, 2013-2024



Source: Global Market Insights

The market size for MWFs is strongly correlated with the growth in the automotive industry. Metal is extensively used to provide structural strength and stability to vehicles. These fluids enhance the life of vehicle parts by reducing wear and thermal deformation. MWFs also provide excellent surface finish in the cutting and welding zone.

North America, is the largest market for MWFs, led by the U.S., where in 2015 the segment generated revenues of more than US$2.5 billion. The European MWFs market is expected to achieve growth of 4% annually through to 2024, led by the German automotive sector. Europe represents around 27% of the world demand for metal working fluids. Russia, Germany, France, Italy and the United Kingdom account for 72% of Europe Region demand. In Asia Pacific, growth in the segment is led by China, Indonesia, India and Japan. Global Market Insights lists Asia Pacific as the largest regional market.

The leading manufacturers are thought to control some 40% of sales in the segment, led by such names as Apar Industries, Castrol Limited, Exxon Mobil Corporation and FUCHS. Other prominent participants include: Lukoil Lubricants and Chevron Phillips Chemical Company LP. As the reader will note, most participants are divisions of major petro-chemical companies, with two of the exceptions; India based Apar Industries (Poweroil brand) and Fuchs Petrolub of Germany, with operations in 40 countries and the largest independent manufacturer of industrial lubricants in the world.

Bio-alternatives

Total Special Fluids reports that the BioLife (vegetable oil based) products have demonstrated good stability performances at 100°C, making them suitable for applications requiring high stability during use, such as MWFs. These products have been tailored for targeted applications with narrow boiling range and ultra-low aromatics, for worker comfort.

A competitive bio-based MWF is also being produced by Castrol, based on castor oil. The success of this MWF, which is produced on an industrial scale, suggests a market opportunity for safer and environmentally friendlier MWFs. This castor based product sells for approximately $1,750 per tonne.

Jatropha Based Technologies

The aforementioned DAW-AEROCIT trials suggest that Jatropha based systems, in operation in the metal working sector, would permit higher tool life and better work piece efficiency, compared to MWFs based on mineral oil. The Italian company, Agroils advertises that its single process Jatropha oil based sub-manufacture 'A-OIL', is able to satisfy in one step, all the critical technical requirements for metal cutting fluids, while traditionally produced vegetable oil based products, require further refining steps to fulfil the following industrial specifications: phosphorus content (< 12 ppm), magnesium and calcium content (<20 ppm), oxidation stability (> 6 hours) and viscosity (< 36 mm2/s).

Polyurethane

Growing calls for greater energy conservation, and a push for low GHG emission materials, are trends which are expected to drive growth in demand for 'greener' polyurethanes. While the persisting weakness in the price of crude oil has driven down the cost of manufacturing polyurethane precursors, impacting on sector profitability, environmental concerns are driving a push for greener, bio-based polyurethanes. Algenesis Materials, a San Diego based company has been able to process Jatropha oil into high quality polyols and use them to create polyurethane for a variety of applications.

Polyurethane is a plastic material or polymer, consisting of organic units linked by carbamate links. Main sources of its formation include di-isocyanates, tri-isocyanates and polyols. Polymeric polyols are generally used to produce other polymers: they are reacted with isocyanates to make polyurethanes used to make mattresses, foam insulation for appliances, home and automotive seats, elastomeric shoe soles, fibers, and adhesives.

Algenesis Materials is proposing the replacement of mineral oil based polyurethane with bio-based product, wherever technically and economically feasible. The US manufacturer foresees whole value chain strategies in certain market segments, including the manufacture of flip-flops, the principal footwear category for perhaps 3 billion people across the developing markets.

Polyurethane (PU) Market Value

Estimated at some US$50 billion in 2015, the global polyurethane market is anticipated to reach US$105.2 billion by 2025, according to a 2017 report by Grand View Research, Inc (http://www.grandviewresearch.com/industry-analysis/polyurethane-pu-market) The polyurethanes market is rather consolidated, but remains competitive due to presence of multinational companies occupying strong positions along the value chain. Bayer, BASF, Huntsman and Dow are the key actors supplying 55% of total demand. Other industry players include Foamex Innovations, British Vita Unlimited, Nippon, Woodbridge Foam Corporation, Recticel, and Mitsui Chemicals.

Polyurethanes Market, By Application

Construction applications accounted for over 30% of 2015 global polyurethanes market share. Flooring, sealants and insulators are some of the major revenue contributing applications. Polyurethane sealants are used to fill gaps in order to prevent air and water leakage. Growing importance towards energy conservation has positively influenced household insulation demand. Automotive applications generated more than US$8 billion in 2016 business. Other growth segments include the footwear and sports footwear segments; in 2015, the Chinese footwear sector alone generated demand worth some US$800 million. Other important market segments include furniture, electronics and packaging.

Polyurethanes Market, By Region

The U.S. polyurethane market is expected to exceed US$12 billion in sales by 2023, with rigid foams projected to enjoy 4% growth in revenues. Regional development, and rising demand for spray PU foam in thermal insulation applications will likely trigger growth in demand for US industry. Grand View Research put 2015 European demand for polyurethane at US$14 billion. It sees growing demand for insulation from low income households for energy efficiency, in tandem with a supportive regulatory environment. The researcher projects that Asia Pacific will witness strong growth, on the back of still buoyant construction spending in China, Japan and India.

Polyurethane Manufactured from Bio-polyols

Natural oil polyols, (NOPs) or bio-polyols, are polyols derived from vegetable oils. The primary use for these materials is in the production of polyurethanes. NOPs all have similar sources and applications, but the materials themselves can be quite different, depending on how they are made. Most NOPs remain similar, chemically, to their parent vegetable oils and as such are prone to becoming rancid. Odor is undesirable in the NOPs, and more importantly, in the end products, in which they are components.

(https://en.wikipedia.org/wiki/Natural_oil_polyols)

Auto-sector A Consumer Pioneer

In 2008, the Ford Motor Company, show-cased polyurethane foam made using NOPs from soy-oil in the seats of its 2008 Mustang. Ford has since placed soy-foam seating in all its North American vehicle platforms. The auto-manufacturing sector is associated with a much of the innovation for the use of NOPs in polyurethane products for interior components such as seats, headrests, armrests, soundproofing, and also for body panels.

From 2010, initially in the US, it has been possible to replace over 50% of petrochemical-based polyols with NOPs for use in slab foams sold into the mass market, furniture and bedding industries. Current manufacturing technology, reportedly, eliminates, or greatly reduces, the odor problem, associated with the use of NOPs from plant source. ("Expanding the Use of Natural Oil Polyols in Urethane Foam Formulations - Rowlands, J. UTECH Conference, Maastricht, the Netherlands. April 2012").

Consumer Preference for Green Products

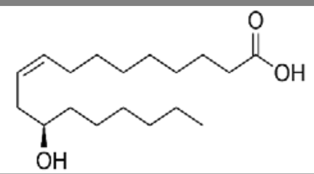
The use of polyols derived from vegetable oils to make polyurethane products only began attracting serious attention during the early years of the current century. The rising cost of petrochemical feedstocks, and an increasing trend across the developed world for consumer preference for 'green' products, prompted demand for new industrial materials. *Niemeyer, Timothy; Patel, Munjal; Geiger, Eric (September 2006). A Further Examination of Soy-Based Polyols in Polyurethane Systems. Salt Lake City, UT: Alliance for the Polyurethane Industry Technical Conference.*

Hydroxyl Count

Jatropha oil, (and various other plant oils) can produce high hydroxyl number polyols. High hydroxyl number polyols are required for rigid foams. Jatropha has a good number of double bonds for basic rigid foam formulation, as does high oleic soya bean oil. As detailed below, any fatty acid with a double bond can be chemically converted to a fatty acid with at least 2 hydroxyl groups. When a double bond is opened chemically, more than one hydroxyl can be added.

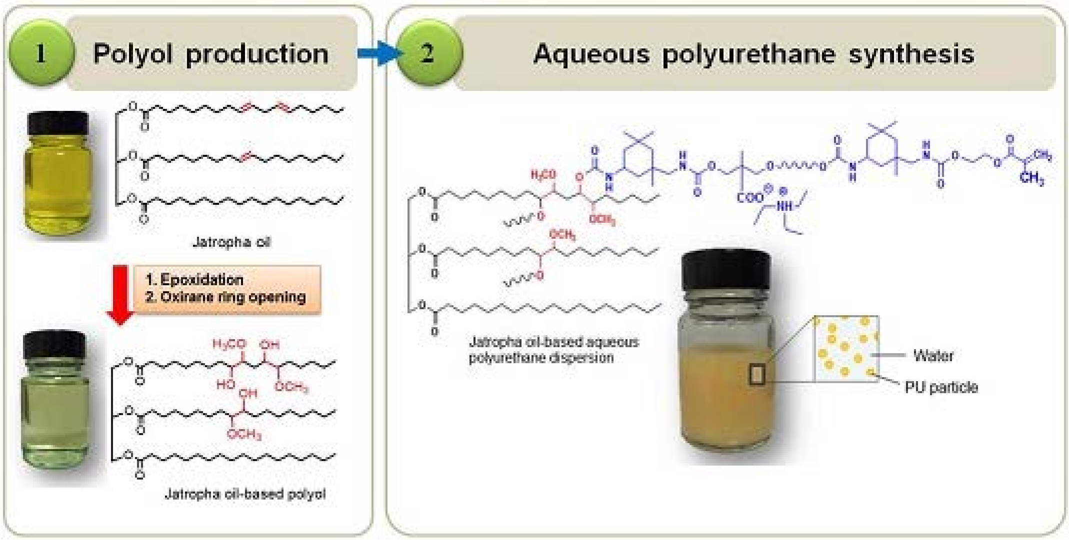
There are a limited number of naturally occurring vegetable oils (triglycerides) which contain the unreacted hydroxyl groups that account for the important reactivity of these polyols. Castor oil is the only commercially available natural oil polyol, or bio-polyol that is produced directly from a plant source: all other NOPs require chemical modification of the oils to convert to polyols. Ninety-percent of the fatty acids that make up castor oil is ricinoleic acid, which has a hydroxyl group on C-12 and a carbon-carbon double bond. Other vegetable oils - such as soy-oil, peanut oil, and canola oil, contain unsaturated fatty acids carbon-carbon double bonds, but lack hydroxyl groups. There are at least five methods available for the conversion of triglycerides or derivatives of triglycerides into polyols. Among these methods, a simple two-step process of epoxidation and ring opening can produce polyols from vegetable oils, including Jatropha. This process is used to introduce hydroxyl groups onto the carbon chain of the fatty acids, and most of these involve oxidation of the C-C double bond to form epoixide. Subsequent hydrolysis of this epoxide leads to polyol production. In addition, polyols can be prepared by ozonolysis. Treatment of the vegetal oils with ozone cleaves the double bond, and esters or alcohols can be made.

Ricinoleic acid structure



Source: Saalah et. Al. 2017, physicochemical properties of Jatropha Oil-Based polyol produced by a two steps method. Molecules: 22(4).

Polyol production using Jatropha oil-based polyol



Source: Saalah et. Al. 2017, physicochemical properties of Jatropha Oil-Based polyol produced by a two steps method. Molecules: 22(4).

Significant Potential for Reduction in GHC

The use of renewable feedstocks for chemical processes has the potential to reduce the polyurethane manufacturing sector's environmental footprint by reducing the usage of non-renewable fossil fuels, and the production of carbon dioxide. PU Magazine International reported (September 26, 2007) that NOP producer, Cargill, had estimated that relative to polyols manufactured from petrochemicals, its BiOH(TM) polyol (NOP based) manufacturing process, produces:

- 36% less carbon dioxide
- A 61% reduction in non-renewable energy use
- A 23% reduction in the total energy demand.

Case Study: Algenesis Materials

Algenesis Materials, a San Diego based company with a mission to replacing petroleum-based polymers with renewable, sustainable, and bio-degradable polymers made from non-food plant oils, has been able to process Jatropha oil into high quality polyols and use them to create polyurethane for a variety of applications. Currently however, the high cost of importing Jatropha into California has rendered it uncommercial for Algenesis to produce price competitive, bio-based polyurethane from this feedstock.

Algenesis has set out to develop superior renewable, and bio-degradable products from bio-based materials. The company has articulated its mission statement as the replacement of "…petrochemicals with renewable, sustainable, and bio-degradable replacement chemicals made from…non-food plant sources". Initially, Algenesis is proposing to focus on the apparel and equipment markets…where it sees a social imperative to use renewable eco-friendly materials and "an ability to pay the small premium associated with a renewable product".

In summer 2017, Algenesis was able to develop a commercially viable sustainable surfboard which is to be marketed with production partner, Arctic Foam. The polyurethane used to make rigid surfboard foams has the same starting monomer as used in the manufacture of soft foams: a major component of shoe soles and flip-flops.

Plastic Sandals & Flip-flops

Globally, some 3 billion people wear sandals or of flip-flops as their primary footwear, with hundreds of millions of these goods being produced each year, most frequently in developing countries. With an average lifespan of only two years, many of these shoes end up in rivers, sewage systems, and waterways, ultimately ending up in the ocean in alarming volumes. The east African coast has seen its beaches littered with discarded flip-flops, with estimates that some 90 tons of this waste ends up in oceans each year.

Waste

Source: Algenesis

The plastic material used in the manufacture of these flip-flops does not degrade, it simply breaks up into smaller and smaller pieces and eventually it can pass as food particles to marine life. A study from Scientific Reports (Article number: 14340, 2016) found that, *"In Indonesia, anthropogenic debris was found in 28% of individual fish and in 55% of all species. Similarly, in the USA, anthropogenic debris was found in 25% of individual fish and in 67% of all species."*

Ocean Sole, a non-profit recycling company, is trying to tackle the issue of polyurethane waste on the east African coast by recycling this waste into new products. The company sees polyurethane pollution as a major ecological disaster, and one with global consequences. In 2016, Ocean Sole recycled nearly 400,000 sandals, but the company argues that *"the only long-term solution is the total replacement of the currently used materials". Erin Smith of Ocean Sole states "I think it's time for us to start looking for an alternative shoe, or an alternative material, to fit that kind of fashion need…products need to evolve".*

Replacing current petroleum based polymers with renewable material in the billions of pairs of flip-flops sold each year, would not only increase the quality of the environment for those living in developing countries, it would benefit the health of our planet by removing the waste generated from the millions of pairs of flip-flops that end up in the ocean each year. Instead of ending up on shorelines and in our oceans, these shoes could be put into compost piles to become soil, and even those that do end up in the ocean or on beaches will bio-degrade rather than become ocean borne fish toxins. These shoes don't need to have a complex design, or longevity. They will be developed to be functional, comfortable, cheap, and easy to produce. "Because they are made from plant oils…and converted…to monomers with simple chemistry…production facilities [can be] in any part of the world…". With these goals in mind, Algenesis and Ocean Sole are focused on the replacement of the non-degradable petroleum based materials with which flip-flops are traditionally manufactured, with a sustainable, bio-degradable replacement.

Bio-based polyurethanes, are expected to produce sandals with the ability to bio-degrade naturally. Algenesis proposes to develop a simple flip-flop in San Diego for the surfing and environmental community (for proof of concept). Once proven, the parties expect there to be a progressive switch away from petroleum-based polyurethane to bio-based polyurethanes for the manufacture of this class of shoes. The concept could have significant implications for African societies, and for the production of Jatropha in Africa. Steve Mayfield, CEO of Algenesis argues that *"The polyol chemical manufacturing is pretty simple chemistry and could easily be done in Africa with minimal investment. Shoe manufacturing is already done there, it would simply require replacing the petroleum polyurethanes with these renewable polyurethanes".* The production of footwear such as sandals and flip-flops, manufactured from renewable, bio-based polyurethane, could potentially have significant benefits for African economies, creating new value chains based on Jatropha from 'farm to foot'.

Simple and easily established shoe factory

Source: Algenesis

About Algenesis

Algenesis is a vertically integrated company - from material sourcing, chemical R&D, manufacturing (under contract), to licensing and sales. The company's immediate focus is on R&D to develop polyurethane foam for the manufacture of surfboard blanks. It is also developing renewable and biodegradable polyurethane foams for shoe soles and compostable beach sandals. Ultimately Algenesis seeks to position itself to be an applied technology licensing and branding company known for renewable and bio-degradable high-quality products.

Biodegradation Behavior of Some Vegetable Oil-based Polymers

(Journal of Polymers and the Environment, Vol. 12, No. 3, July 2004) Randal L. Shogren,1,4 Zoran Petrovic,3 Zengshe Liu,2 and Sevim Z. Erhan2

"The potential biodegradability of several vegetable oil-based polymers was assessed by respirometry in soil for 60–100 days at temperatures of 30–58 C. Films of soybean oil and linseed oil which were oxidatively polymerized (Co catalyst) on a kraft paper support were 90%–100% mineralized to CO2 after 70 days at 30 C. Mineralization of polymerized tung oil to CO2 was much slower than soy or linseed oils. Mineralization of epoxy resins made from epoxidized soybean oil (ESO) and aliphatic dicarboxylic acids was rapid while mineralization of similar resins made with a triacid (citric) was slower. There was no significant degradation of polyamine/ESO resins after 100 days at 58 C. Mineralization of the available carbon in vegetable oil polyurethanes and cationically polymerized ESO was less than 7.5% after 70 days at 30 C and 25 days at 55 C compared to 100% for soybean oil. From these results, it appears that triglycerides highly cross-linked with non-degradable linkages are not biodegradable to a significant extent, while triglycerides cross-linked with hydrolysable bonds such as esters remain biodegradable".

The research published under the reference above concluded that "*cross-linking triglycerides with non-degradable linkages results in loss of biodegradability…Alternatively, some glycerol ester bonds might be cleaved but further metabolism of the fatty acids would be blocked by the branch points. The relatively rapid biodegradation of oxidatively polymerized soybean and linseed oils suggests that there are likely parts of the network which contain chain ends having groups susceptible to biodegradation such as carboxylic acid or alcohols. The cross-linking density of these networks is also likely lower than the other systems due to the formation of oxidized species in addition to radical combination and cross-linking. Triglyceride networks containing hydrolysable ester bonds, especially linear diesters, are biodegraded fairly rapidly in soil*".

The study examined rates of biodegradation in soil only, and it concluded that "*different microbial populations and physical conditions are present in different environments such as activated wastewater treatment sludge, composting centres, rivers, oceans. Different rates of biodegradation would be expected for polymerized vegetable oils in these different environments, though similar trends might be expected among the different samples examined in the research"*.

Biopesticides

Jatropha, Usage and Research

HAB's 2015 review of the Jatropha sector: Future Harvest, found a widespread interest in Jatropha derived phorbol esters for use in the formulation of bio-pesticides. Jatropha kernel oil and aqueous extracts from the oil, have been used in the control of cotton boll worm and other pests of pulses, potatoes and corn for some time: (Kaushik and Kumar, 2004). The former SGB Inc used formulations of Jatropha oil sprays as part of an integrated pest management programme to control spider mites, bud mites, mealy bugs and thrips on its Guatemala Jatropha plantation. This effectively eliminated the need for expensive commercial miticides. After reviewing more than 100 peer reviewed studies, Ratnadass & Wink (2012 - see below), concluded that extracts of Jatropha species, (in particular *Jatropha curcas*) leaves, seeds and oil are repellent, deterrent or toxic, either by contact or ingestion, to several agricultural pests.

With increasing consumer awareness of the potential health hazards associated with the application and persistence of synthetic insecticides, there has been increasing consumer demand in the US and Europe for "natural" insecticides or "bio-insecticides". However, commercialization of Jatropha based pesticide products, will require significant scientific, technical and regulatory input and evaluation.

It has been understood for some time that for effective use as a bio-insecticidal agent, Jatropha originated phorbol esters will need to be 'harvested' as stable, high-integrity chemicals, and this will require the development of a commercial process for their extraction from the oil and or other parts of the plant. JatroSolutions, the German crop science company, reports that it has upscaled a method of phorbol ester isolation from Jatropha oil. The Italian process engineering company, Agroils Technologies SPA, is researching the potential to 'harvest' phorbol esters in the company's proprietary 'aqueous phase' detoxification process. Agroils advises that its experience has been that phorbol esters captured in the dried product obtained from the company's 'aqueous phase' remain relatively stable with good biological activity, which contrasts with other references to greater stability in oil suspensions.

Technology Challenges

In common toxic Jatropha the presence of phorbol esters in Jatropha oil can be expected to render the oil unacceptable as a control agent on food crops, and certainly not without extensive testing to validate the longevity of the phorbol esters on treated plants. Conversely, there may be an opportunity to target non-food crops like cotton, biofuel feedstocks, and the nursery and floriculture sectors with insecticide products developed from the oil of the common toxic variety.

Once extracted, Jatropha phorbol esters rapidly lose activity at room temperature and on exposure to strong light. It will be necessary therefore, to develop effective storage technologies to maintain their integrity. Moreover, phorbol esters are easily broken down in the natural environment, so technologies must be developed to retain their activity for the time required for them to be effective as bio-insecticides, whilst still allowing them to biodegrade after use.

In a 2012 publication (The Phorbol Ester Fraction from *Jatropha curcas* Seed Oil: Potential and Limits for Crop Protection against Insect Pests. Alain Ratnadass and Michael Wink; Int J Mol Sci 2012; 13(12): 16157-16171.) Ratnadass and Wink concluded that phorbol esters are most stable in oil, in which they are relatively heat resistant and enjoy good shelf life. Ratnadass & Wink noted that the most effective Jatropha extracts included toxic diterpenes, and in particular, phorbol esters. It was further noted that while it was unlikely that Jatropha would be cultivated simply for its insecticidal properties, compounds such as phorbol esters represented valuable co-products alongside the plant's primary products. The study proposed that where the crop was grown in isolated or landlocked countries – for example in the Sahelian countries –where Jatropha oil is produced for fuel and remains competitive with imported fuels, then the phorbol ester extracts could be seen as a cheap crop protection product for farming communities priced out of the market for synthetic chemical based crop protection. Ratnadass & Wink, concluded that "the study of the insecticidal effects of (Jatropha) seed oil, particularly phorbol esters, and their evaluation in real conditions, should be given priority, rather than screening of novel bioactive substances."

Jatropha contains a variety of toxic compounds including curcin and hydrogen cyanide (found in seed oil), but the primary focus for biocidal action has been directed at the phorbol ester fraction. Despite the fact that the phorbol ester fraction from the seed oil of Jatropha has been reported as a promising component in biopesticides for crop protection, both 'pre' and 'post' harvest, Ratnadass & Wink noted that commercialisation of Jatropha based bio-pesticides has yet to occur. Ratnadass et al advance the following possible reasons:

- Use of phorbol esters on stored food ingredients post-harvest could leave toxic residues
- Unknown impact of decomposing phorbol esters on field environment
- Biodegradability and low persistence in soil, conflict with the requirement for long action against pests
- High variability of phorbol ester content
- Standardisation of chemically complex extracts
- Potential phyto-toxicity
- Cost of development & registration/regulatory approval costs; these involve very much the same costs as a registration and approval of a synthetic pesticide
- Difficulty of obtaining patents for phorbol ester extracts.

Crop Opportunity: Cotton

The USDA reports that in 2016, more than 10 million acres of cotton were planted in the USA. It is believed that circa 60% of the US cotton crop is treated with insecticides to control a variety of arthropod pests including thrips and spider mites, at an average cost of ~$56 per acre, or $336 million (approximately) per year. If Jatropha oil as a bio-insecticide could capture just 5% of this US market (perhaps targeting only thrips, spider mites and similar "sucking" pests), it would represent a revenue opportunity of $17 million per annum. In cotton, the most susceptible growing periods affected by thrips and mites are the first month beginning from germination, and the month beginning with bud formation. Assuming ~4 applications per growing season, or a total of 2.4 litres/acre/season, and addressing just 5% of the cotton acreage, would create demand for some 720,000 litres annually.

Opportunity: Nursery and Floriculture Sectors

According to the USDA the total US floriculture sector occupied 60,000 acres (both indoor and outdoor cultivation) in 2015. Pesticide usage on these crops is not available, but thrips and spider mites are common problems that could be mitigated with Jatropha oil based bio-insecticides. Expert opinion (Dr R Schmidt of Resogen Inc) suggest that the floriculture sector would adopt a similar application rate and concentration as projected for the cotton crop.

According to 'Markets and Markets Research', the world-wide 2015 bio-insecticide market for *thrip control alone* was valued at $170 million, and projected to grow to $418 Million by 2020. Similarly, the global acaricide (mites and ticks) market is estimated to reach $275 million by 2019.

Jatropha oil derived bio-insecticide products may also be appropriate for a variety of peeled-fruit crops, such as bananas, most citrus, avocadoes, etc. The products may also find acceptable application for those crops for which the edible portion, is not directly in contact with insecticidal sprays. Examples would include peanuts, sugar beets, onions, etc. These crops could provide additional market opportunities for Jatropha derived bio-insecticides, following appropriate testing and certification.

For comparison, the global Neem Oil market was estimated to have generated sales with a value of $495 million in 2013, according to Transparency Market Research, with scope to achieve $1.1 Billion in 2019. This is corroborated by Brick Insights, another market research agency which has forecast that the global Neem Oil extract market will grow to $1.4 Billion by 2022.

Carbon Fibre

A $10bn Market Growing in Excess of 5% Annually

Carbon fiber (CF) is an expensive but highly desirable lightweight high-performance material that is utilized in both structural and non-structural applications. The high cost of CF has restricted its usage to the likes of aircraft and aerospace parts, high end automobiles and top tiered sporting equipment. Today, more than 90% of CF is manufactured from petroleum-based polyacrylonitrile (PAN) precursor. More than 50% of the manufacturing cost of CF is attributable to the precursor production alone, which is one of the barriers to the widespread use of CF and CF composites. Lignin, the second most abundant organic material on the planet, has long been considered a desirable raw material in the CF manufacturing field. Unfortunately, typical lignins are heteropolymeric, and do not yield a lignin-derived CF that satisfies both strength and cost requirements. Resolute Genetics llc (a San Diego based company) has been collaborating with scientists at the University of North Texas (UNT) to demonstrate that an unusual homopolymeric lignin in the seed coat of Jatropha can be a suitable precursor for CF generation. Scientists now with the BioDiscovery Institute of UNT, discovered a novel lignin (C-lignin) polymer in the seed coats of several plant species including *Jatropha curcas*. The "C" in C-lignin stands for Catechyl lignin, a homopolymer composed of caffeyl alcohol; one of the several precursor types (monolignols) of which lignins are composed. Caffeyl alcohols are uncommon among plants, and homopolymers of caffeyl alcohols (or any lignin precursor) are rare. Because the seed coat of Jatropha has a homo-polymeric lignin, there is now hope that Jatropha-derived lignin will turn out to be a cheaper precursor than the traditional petroleum-derived PAN precursors. If C-lignin, harvested from the seed coatings of *Jatropha curcas*, is found to represent a cost effective and technologically acceptable renewable source for the production of CF, then Resogen plans on targeting production of Jatropha on displaced cotton and citrus acres in the Southern USA.

UNT, in collaboration with Resogen and chemical scientists and engineers from Texas A&M University, University of Tennessee, Knoxville and Oak Ridge National Laboratory, are seeking $2m in funding over three years from the US Department of Energy to demonstrate proof of concept for both the economics of growing Jatropha in the Southern USA and for C-lignin extraction and conversion to CF. The former will require a solution for the traditionally core product from Jatropha, its high-quality oil. With crude oil currently trading below $500/mt, CJO cannot be considered an economic feedstock for the production of biodiesel. Resogen is intending to monetize the oil for the production of renewable polyurethane or as a biopesticidal agent. On this basis, the company is hoping that commercial activity can be scaled up from 2021.

Growth Driven by Value-Adding Applications

March 17th, 2016 the media platform, Composites World published an article on the demand outlook for advanced fibres. In respect of carbon fibre the article noted that historically, markets for carbon fibre have gone through boom/bust cycles, making it difficult for fibre manufacturers to predict capacity needs. The article noted that then in early 2016, demand was rising, and as detailed in the table below from Composites Forecasts and Consulting LLC's (Mesa, AZ, US), demand looks likely to outstrip supply by 2020. The forecasting agency, was further cited, projecting compound annual growth in demand for carbon fibre at more than 9%, through 2024. Looking back to 2014, Mike Canario, VP and GM Americas at carbon fibre manufacturer Hexcel, was bullish on segment growth: looking ahead, through 2018, he offered that carbon fibre was expected to growth healthily in every major market:

- Sports and leisure: 5.7% CAGR
- Aerospace: 10% CAGR
- Industrial: 14.4% CAGR
- Overall: 12.3% CAGR

In 2015, the world CF supply was about 93,100 mt, whereas demand in 2020 is projected to increase to 150,000 mt.

Carbon fibre demand and supply, metric tonnes (mt)

	Carbon fiber demand	Carbon fiber supply (nameplate)	Carbon fiber supply (actual)*
2010	48,370	79,650	47,790
2015	82,400	143,595	93,171
2020 (est.)	150,200	180,600	129,965

**Actual output is less than nameplate, due to capacity knockdown.*

Source: Composites World

Carbon Fibre Market

According to market researcher Chris Red, principal at Composites Forecasts and Consulting LLC, some 75% of the world's carbon fibre is "consumed by the industrial sector" and that this will continue to be the source of the greatest growth. The three big segments with which carbon fibre is typically identified are Aerospace, Consumer & Recreation and Industrial.

Aerospace

As a lightweight high-performance material, CF-reinforced composites have been used in a variety of applications such as aircraft and spacecraft parts. Important programmes include:

- the Boeing 787
- the Airbus A350 XWB
- the F-35 Lightning II
- the 777X wing programme.

Observers note that without a large aero-composites programme to spur substantial carbon fibre manufacturing expansion, it remains unclear whether carbon fibre will be chosen in the manufacture of fuselages. The next major aviation programmes are expected to be the replacement for the Airbus A320 and the Boeing 737. These are expected in the 2025-2030 timeframe and although it is considered likely that the wings for these series, will be carbon fibre composites, it remains to be seen whether carbon fibre will be chosen for the fuselages.

Industrial (including the automotive and energy sectors)

Chris Red (Composites Forecasts and Consulting LLC) has predicted that the automotive market "*is poised to become the carbon fiber juggernaut for which composites industry proponents have long hoped*". Future automobiles are likely to comprise a mix of steel, aluminium and composites, applied as mechanical requirements demand and as cost permits. Today, among other applications, CF is being used in the construction of high-end automobiles and sporting good equipment. It is expected that CF will penetrate 20% of the luxury car market by 2020.

Pressure vessels for storage and transport of compressed and liquefied natural gas in automotive and fleet applications, are expected to drive substantial carbon fibre growth, particularly in Asia, South America and parts of Europe. Within the wind energy sector, demand for carbon fibre composites is expected to run at 8% CAGR. CF is being used in the construction of modern wind turbines.

(http://www.compositesworld.com/articles/supply-and-demand-advanced-fibers-2016).

Jatropha Derived Homo-polymeric Lignin

CF composites are considered too expensive for high volume automotive production and other applications. Currently, more than 90% of CFs are manufactured from petroleum-based polyacrylonitrile (PAN) precursor. PAN is made by the free radical polymerization of acrylonitrile, which in turn is produced by catalytic ammoxidation of propylene, a co-product in petroleum refining processes. The precursors account for more than 50% of the manufacturing cost, and their high price is one of the barriers to the widespread use of CF. (Milbrandt A & Booth S (2016) Carbon Fiber from Biomass. (NREL (National Renewable Energy Laboratory (NREL), Golden, CO (United States))). Alternative precursors to reduce CF cost have been investigated over the years. These include petroleum-based alternative fibre, such as textile grade PAN and polyolefein (PO), and biomass-derived precursors, such as Rayon, lignin, glycerol, and lignocellulosic sugars. (Frank E, Steudle LM, Ingildeev D, Spörl JM, & Buchmeiser MR (2014) Carbon fibres: precursor systems, processing, structure, and properties. Angewandte Chemie International Edition 53(21):5262-5298.)

The challenge for the CF manufacturing sector is to find a low-cost, non-PAN precursor. Mike Canario of Hexcel, speaking at Composites World's Carbon Fiber 2014 conference in La Jolla, CA, US noted the following costs to manufacture the two basic types of carbon fibre: Aerospace grade: $85,000 to $220,000 mt and Industrial grade: $25,000 to $95,000 mt. Canario, further observed that carbon fibre ramp-up is not cheap: it takes 2 kg of PAN to produce 1 kg of carbon fiber. Further, the high-temperature ovens used to convert PAN to carbon fiber are energy- and capital-intensive. Finally, construction and commissioning of a new carbon fibre plant can take 12 to 18 months, which prolongs return on capital expansion investment.

Dr Robert Schmidt of Resogen notes that "*for over a decade, efforts have been made to come up with a cheaper precursor than PAN. Lignin was the biological hopeful, but decoupling and purifying lignin precursors from typical plant lignins, followed by synthesizing homo-polymeric lignin, was not cost effective*". Because the seed coat of Jatropha has a homo-polymeric lignin, there is now hope, that Jatropha derived lignin will turn out to be a cheaper precursor than PAN, whilst also being renewable.

C-Lignin

Lignin has been considered a desirable raw material in the emerging bio-based CF manufacturing field. The presence of naturally high levels of C-lignin in *Jatropha curcas* seed coats, suggests a novel source of this polymer. C-lignin, is a linear homo-polymer biologically synthesized from a caffeyl alcohol. Early studies demonstrated the great potential of this new polymer in the production of bio-based CF with excellent thermo-stability and high carbon yield during carbonization (Nar M, et al. (2016) Superior plant based carbon fibers from electro-spun poly-(caffeyl alcohol) lignin. Carbon 103:372-383.).

Current technologies do not yet yield a lignin-derived CF that satisfies both strength and cost requirements due to lignin's heterogeneous properties. Hetero-polymeric lignin, as is typically found in plant matter, can be carbonized, but the final product does not have the tensile strength and flexibility of the homo-polymeric PAN-based CF.

Additional Industrial Applications

Because CJO has an exceptional fatty acid profile and cold flow properties it is highly suitable for the manufacture of industrial lubricants, hydraulic fluids, dielectric coolants and surfactants, a global market opportunity generating annual revenues in excess of $36bn. The regulatory and consumer pressure for 'greener' and healthier products, is providing an opportunity for bio-based technologies to erode the market for the dominant technologies based on mineral oil. In a number of cases, the Jatropha fractions have superior technical superiority to competing bio-components.

Industrial Lubricants

There have been a number of researches into the suitability of Jatropha oil for the production of clean, effective, renewable lubricant oil. Vegetable oil can be used as a bio-lubricant either by blending it with a commercial lubricant or by converting the vegetable oil into fatty acid methyl ester (FAME) for use as lubricant additive for internal combustion engines. Research conducted by the University of Malaya's Centre for Energy Sciences, Department of Mechanical Engineering by H.H. Masjuki and others (2011 IEEE First Conference on Clean Energy and Technology CET, concluded that Jatropha oil "had shown a high potential as an alternative lubricant in conventional internal combustion engines as an anti-wear lubricant additive, as well as the enhancer of lubricating performance".

Gunam Resul, M.F.M., and others of The Department of Chemical and Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia produced a paper entitled 'Synthesis of Biodegradable Lubricant from Jatropha Oil with High Content of Free Fatty Acids'. The paper considered Jatropha oil's potential application as a biodegradable lubricant. The study found that the lubricity characteristics of Jatropha based bio-lubricant, including pour point, viscosity and thermal oxidative stability, were comparable with other vegetable oil based lubricants. It concluded that after transesterification with trimethylol propane (TMP), Jatropha oil derived lubricant "behaves as an excellent lubricant" and the paper postulated that "this could be a new way of development of Jatropha oil...".

In August 2017, the research provider Transparency Market Research (TMR), released an update on the global independently manufactured industrial lubricants market. (https://www.transparencymarketresearch.com/pressrelease/lubricant-market-opportunity-analysis-independent-manufacturers.htm) TMR estimates that the global independent manufacturers market will reach a valuation of some US$9.5bn by the end of 2025 (US$6.8bn in 2016), achieving CAGR of 3.80% over the period. TMR further notes that in 2016, the mineral lubricants product segment represented almost 61% of the market. However, TMR is projecting that the mineral oil product segment can be expected to sustain nominal decline over the forecast period, as synthetic lubricants expand their share.

While the independent sector is dominated by just four companies with a combined market share of circa 58% (the German manufacturer FUCHS accounting for 37%), TMR projects that "*the presence of a large number of small players stiffens competition in the global independent lubricant manufacturers market*". The researcher also notes that "*the emergence of bio-based lubricants and the vast growth opportunities on account of demand for these products is expected to intensify competition in the market*".

Independent lubricant manufacturers typically purchase base oils from major oil suppliers. These manufacturers then blend the oils with additives to make lubricants for industrial manufacturing customers and automobile makers. Independent lubricant manufacturers primarily focus on manufacturing and marketing lubricants for specialties and niche businesses. TMR describes demand for bio-based lubricants as "*massive*". The 2017 report from TMR notes that the implementation of environment protection regulations across key regional markets has led to "*…massive demand for high-quality lubricants*". The expectation within the sector is that growing regulatory and consumer pressure for greater protection of the environment, will drive demand for bio-based lubricants, thereby presenting growth opportunities for independent lubricant manufacturers that offer bio-based products. A fundamental challenge for manufacturers of these products will be the achievement of economic price points providing both compelling pricing for consumers and acceptable margins for the producers.

Readers will note that the 'independent' segment of the industrial lubricants market represents only around 12% of the global segment, which researchers estimated at $55.7bn in 2015, and is projected to expand at CAGR of 2.5% from 2016 to 2021.(http://www.marketsandmarkets.com/Market-Reports/industrial-lubricants-market-84594070.html).

Dielectric Coolants

Dielectric liquids are used as electrical insulators in high voltage applications, e.g. transformers, capacitors, high voltage cables, and switchgear (namely high voltage switchgear). Their function is to provide electrical insulation, suppress corona and arcing, and to serve as a coolant. Transformer oil or insulating oil is usually a highly refined mineral oil that remains stable at high temperatures and that has excellent electrical insulation properties. These oils therefore form a critical part of the insulation system for transformers, providing insulation and coolant properties.

Transformer oil, also known as dielectric insulating oil, is used as a coolant and as insulation in electric transformers. Additionally, it aids to preserve the core and winding, fully immersed inside oil and also prevents direct contact of atmospheric oxygen with cellulose made paper insulation of windings, which is susceptible to oxidation. According to a September 2016 report by Market Research Future Report, the global Transformer oil market was valued at USD 2,100 million in 2015 and is expected to be valued at USD 3,641.1 million by the end of 2022, expanding at a CAGR of 8.29 %. "Global Transformer Oil Market - Trends & Forecast, 2016-2022".

The global transformer oil market is dominated by mineral oil forms namely, naphthenic and paraffinic, which accounts for 90.0% of the overall market. However, increasing environmental concerns and increasingly stringent regulations regarding fire safety, are anticipated to boost market demand for bio-based alternatives.

In their paper, Production and Characterisation of Biobased Transformer Oil from *Jatropha curcas* Seed, (Journal of Physical Science, Vol.24(2),49-61 2013, Garba, Gimba and Emmanuel (from Department of Chemistry, Ahmadu Bello University, P.M.B. 1044, Zaira, Nigeria), explored the production of transformer oil from Jatropha that was non-toxic, non-flammable, bio-degradable and which was able to extend and enhance transformer functionality. The team from Ahmadu Bello University also examined whether the oil would enable the transformer to carry higher loads during peak demand periods without leading to premature insulation failure. The discussion below borrows extensively from the Ahmadu Bello University paper referenced above.

Viscosity is considered to be the most important property of transformer oil; it affects the operation of fuel injection systems, especially at low temperatures when an increase in viscosity impacts on the fluidity of the fuel. Jatropha seed oil has been measured with a viscosity of 8.2 cSt which is close to that of diesel fuels. This level of viscosity is considered good for ease of pumping and atomising fuel. The Ahmadu Bello team also noted that the flash point of Jatropha oil is 150 degrees Celsius (oils with flash points above 66 degrees Celsius are considered safe oils; Makkar, H.P.S., Becker, K. & Schmook, B. (1998). Edible provenance of *Jatropha Curcas*. Plant Foods Human Nutr., 52, 31-36.). This indicates that Jatropha oil can prevent auto ignition and fire hazard at high temperatures during transportation and storage.

The cloud point for Jatropha oil is 14 degrees Celsius which indicates that Jatropha oil can perform satisfactorily even in cold climatic conditions. The oil also has a low pour point of 4 degrees Celsius, whereas higher pour points limit the use of oils in transformers in cold climatic conditions. The inquiry by the team at Ahmadu Bello University concluded that refined Jatropha oil is of good quality and that the values obtained for the oil by the team corresponded well with ASTM specifications*. As a bio-degradable oil suitable for use in transformers, the team concluded that there could be a significant market for Jatropha oil.

Characteristics of *Jatropha curcas* seed oil

Property	Value
Saponification value	155 mg KOH g–1 oil
Peroxide value	7.20 meq g–1 oil
Iodine value	51.27 g 100 g–1 oil
Free fatty acids	0.0718 mg KOH g–1 oil
Acid value	0.1428 mg KOH g–1 oil
Viscosity	8.2 cSt
Boiling point	124°C
Specific gravity	0.8480
Flash point	150°C
Cloud point	14°C
pH	5.2
Dielectric strength	22 kV
Pour point	4°C
Density at 27°C	0.725 g cm–3

Source:
Production and Characterisation of Biobased Transformer Oil from Jatropha curcas Seed, Journal of Physical Science, Vol.24(2),49-61 2013.

Garba, Gimba and Emmanuel. Department of Chemistry, Ahmadu Bello University, Zaira, Nigeria

* ASTM D6871 - 03(2008) - Standard Specification for Natural (Vegetable Oil) Ester Fluids Used in Electrical Apparatus: This specification covers a high fire point natural vegetable oil ester insulating fluid for use as a dielectric and cooling medium in new and existing power and distribution electrical apparatus such as transformers and attendant equipment. The physical property requirement including colour, fire point, flash point, pour point, relative density, and viscosity shall be tested to meet

the requirements prescribed. The electrical property requirements including dielectric breakdown voltage, dissipation factor, and gassing tendency shall be tested to meet the requirements prescribed. The chemical requirements including corrosive sulphur, neutralization number, PCB content, and water shall be tested to meet the requirements prescribed.

Surfactants

The annual global production of surfactants is estimated at some 15 million metric tons with a value of circa $30bn (Neil A Burns LLC). Industry references indicate that the global surfactant market will expand to exceed $40bn in value by 2020.Approximately 50% of total production is used in the manufacture of detergents, while the other 50% is utilised in a wide variety of industrial applications including amongst others, production of chemicals, textiles, cosmetics and healthcare items.

The largest proportion of surfactants has a petroleum base and is considered to be environmentally hazardous. The eco-toxicity, bio-accumulation and bio-degradability of surfactants are pressing issues for better management of our impact on the environment. In this context there is increasing interest in bio-surfactants including those produced from Jatropha oil. However, it must compete in this segment with Palm Kernel Oil which has an estimated capacity of some 3.0m metric tonnes of fatty alcohol capacity annually.

Sophorolipids (SLs) are glycolipidic bio-surfactants that have been demonstrated to be suitable for replacement of petroleum based surfactants in detergents. SLs have been described as "a kind of microbial extracellular bio-surfactants produced by non-pathogenic yeasts" Jatropha Oil Derived Sophorolipids: Production & Characterization as Laundry Detergent Additive; Kasturi Joshi-Navare, Poonam Khanvilkar and Asmita Prabhune; Biochemistry Research International Volume 2013 (13) Article ID 169797. Bio-surfactants have to compete with petroleum based compounds in terms of cost, functionality and production capacity (Makkar and Cameotra 2002). With raw materials representing 10%-30% of overall cost of production, there is considerable interest in finding economical and renewable sources.

Kasturi Joshi-Navare, Poonam Khanvilkar and Asmita Prabhune have explored the utility of Jatropha oil as a raw material for the synthesis of SLs. Jatropha oil is largely composed (80%-95%) of saturated and unsaturated fatty acids with chain lengths of 16 or 18 carbon atoms, which Joshi-Navare et al confirm is ideal for production of SLs. SLs are synthesised using C.bombicola, a robust strain of yeast which is able to survive and produce SLs in the presence of Jatropha alkaloids. Joshi-Navare et al confirmed also that Jatropha oil derived SLs were recognised as having desirable (for surfactants) wetting properties, contact angle reduction and antibacterial action. Jatropha SLs demonstrated efficiency in stain removal and when used as detergent, showed improved performance and yet were bio-degradable and non-toxic.

Company Profiles

The companies detailed herein all have the development of Jatropha as a viable commercial crop, at the core of their research and development efforts. The differences between the companies are partly driven by the profile of their different shareholder bases, and partly by cultural instincts. The European names, Jatropower and JatroSolutions, have focused on Jatropha as crop for marginal agricultural environments, where it could play a role in alleviating poverty and producing income on soils largely unsuited to the production of food. The Singaporean company JOil, has led an ambitious programme of scientific research, exploring all avenues for the development of Jatropha as an important commercial crop, for both simple and sophisticated farming systems, including the development of a demonstration farm in Ghana. JOil has been unique in investing in the mid-stream sector, by taking a stake in the Italian processing company, Agroils. In the Americas, and not all the companies are discussed herein, the focus has been on the development of Jatropha for professional, commercial farming, and in the case of Resogen, for broad acre cultivation in temperate climates as an annual, or rotation crop.

Jatronergy

Introduction

Jatronergy, a subsidiary of Grupo Lodemo (a petroleum products business), is a crop science company focused on the breeding and agronomy of *Jatropha curcas* (Jatropha). The company's breeding and agronomy research facility occupies some 25 hectares about 150 km Northeast of Merida, in Yucatan, Mexico. Jatronergy reports that in 2017 its hybrid varieties are yielding up to 4.5 ton/ha/year of dry seed, compared with 0.25mt/ha annually in 2012. Jatronergy claims that this performance improvement derives from:

- the execution of an aggressive breeding programme
- $2.2m of focused investment in research and development since 2013
- the utilization of high genetic diversity (including non-toxic varieties)
- efficient management of operational activities.

Status of Operations

Today, Jatronergy hybrid varieties are being trialed across some 20 hectares in the northern Mexico states of Sinaloa, Sonora, and Baja California Sur. In the initial year of trialing, the company reports that its hybrid varieties achieved yields of 3.5-4.0 mt of dry seed per hectare. Production is presently utilized traditionally for oil, meal, kernels, shells and bio-mass. The company is projecting the area planted to Jatropha across Mexico, rising to some 50,000 ha over the next few years. There appear to few data for the area planted to Jatropha today, but Jatronergy estimates about 8,000 ha across 6 of Mexico's 32 states. The company notes that these are uncertified materials, traditionally farmed and likely to be producing very small crops. Jatronergy is also intending to commence testing its hybrid varieties in South America and West Africa.

The company offers its hybrid planting material as:

- certified seed & cuttings
- rooted plants
- licensed homozygous inbred parents for local seed production
- tested high yielding varieties.

Additionally, Jatronergy offers a range of cultivation and breeding specific services including:

- double haploid (DH) technology services to produce homozygous inbred parents
- agronomy technological services
- project design.

Strategic Approach

Jatronergy is deeply conscious of the bad publicity that Jatropha has attracted as a result of being over-hyped during the period 1990-2010, and because of the numerous projects around the world that failed due to misconceptions about the species, and because of flawed project strategies. The company takes a responsible approach to the sales and marketing of its products, with the objective of ensuring that its grower customers are successful with the planting materials acquired, and the agronomy regimes proposed. However, the company accepts that science and technology around Jatropha has must continue to develop, including specifically crop management/field mechanization. Jatronergy is adapting other crop management equipment for Jatropha cultivation. For open field seed planting, the company has adapted a corn-planter, but it accepts that harvesting equipment remains a considerable challenge.

Hardman Agribusiness Comment

Jatronergy is a traditional Jatropha crop science company, with a strategy of research and development led production of high-yielding Jatropha hybrid varieties, for sale to commercial farmers. Notwithstanding the poor press that Jatropha has attracted, and the failure (so far) of the crop to develop a scaled foothold in the commercial farming sector, Jatropha continues to attract its adherents, prepared to invest significant capital in unique development programmes. JOil, Jatropower, JatroSolutions and SGB/Resogen, have between them more than 45 years of research and development experience of Jatropha. In India, the petro-chemical giant, Reliance Industries continues to quietly work on the development of the species. Certain of the Jatropha crop science companies, including Jatoil (Australia/Vietnam), Quinvita (Cape Verde/Belgium and at one time the lead voice in the R&D segment) and SGB (now Resogen), have either given up their research or scaled it back significantly, but collectively across the sector it would not be an exaggeration to talk of a century of combined focus on developing Jatropha as a commercial species, stretching from Asia (and India in particular), to Africa and Latin America. Given the very early stage status of the commercial cultivation of the crop, there would appear to be a case for companies like Jatronergy seeking alliances or partnerships with some of their longstanding crop science competitors in this sector.

Jatropower AG

JATROPOWER AG (JATROPOWER) combines 16 years of research into Jatropha with more than 22 years of experience of the crop. Research and development, the breeding programme, and the commercial operations are led by group CEO and Chief Scientist, Dr George Francis. Managed and owned by a small group of former Swiss industrialists with relevant life sciences sector experience, together with Dr Francis, JATROPOWER's proprietary planting material (which incorporates all the breeding material of the former Quinvita NV) has now been cultivated over some 8,000ha of centralised and smallholder farms.

Within the sector the company is renowned for its focus on edible or non-toxic Jatropha and for a concentration on development of plants able to produce commercially acceptable harvests in degraded soils in semi-arid climates where the crop does not compete with food production. In this context, Jatropower remains faithful to the traditional strategies for Jatropha cultivation, which focus on poverty alleviation amongst smallholder farmers operating in marginal agricultural environments. Jatropower has demonstrated the efficacy of the high protein kernel meal from edible Jatropha as an animal feed thus strengthening the traditional Jatropha business model.

In addition to its well-resourced technical division, which drives the company's ongoing R&D programme, JATROPOWER represents itself as a commercial partner for businesses seeking to farm Jatropha, able to supply a number of proven lines of both edible and common toxic varieties, and to support a new Jatropha project from conception to post implementation. In 2016, the company sold approximately 1.4 metric tonnes of elite seeds for planting, of which 0.9 mt was common-toxic variety, and 0.5 mt was non-toxic material. The company sold commercial volumes of its first elite F1 hybrid jatropha seeds in 2016.

Company & Management

Founded in 2007, JATROPOWER is a privately held Swiss company located in Baar, Canton of Zug. The company owns and is developing a collection of elite edible and common toxic *Jatropha curcas* varieties from a highly diverse germplasm base of 650 accessions. Group CEO, Dr George Francis, is an alumnus of Hohenheim University in Stuttgart, where Dr Francis has been a central figure in the university's 30+ year Jatropha research programme.

Business Operations

Jatropower's primary business focus is the sale of seeds to an international client base, which provides improved Jatropha planting materials to smallholder farmers. Today however, that client base is primarily, but not only, working with smallholder farmers in Sub-Saharan Africa. The farmers using Jatropower's Jatropha hybrids, follow a traditional Jatropha business model, selling crude Jatropha oil (CJO) as fuel, and using the seed cake, shell and kernel husks as fertilizer. Jatropower estimates that the farmers using its materials, and having harvestable operations, are producing some 2,000 mt of CJO annually.

Research & Development Focus

Jatropower is concentrating on the further improvement of its genetic material, with a particular focus on its non-toxic lines. There is a focus on seed productivity, resistance to a variety of specified diseases, and on cultivation/agronomy regimes. True to traditional Jatropha sector objectives, (supporting smallholder farmers), the company is also working to provide its client base with small scale, but scalable seed processing technologies, especially for edible jatropha resulting in three different products, namely, oil, kernel meal and shell pellets. Responding to demand from the market, Jatropower is also experimenting with intensive cultivation systems that would result is remunerable yields during the first year after planting.

Hardman Agribusiness Comment

Jatropower has proven to be a survivor in the Jatropha sector, with a lean, focused operation, committed to the development of non-toxic and common-toxic Jatropha for use in traditional agricultural systems across the developing world. The company has not had the comparatively large development budgets of peers such as the former SGB Inc (now Resogen), or JOil in Singapore, so it has kept its focus narrower.

JOil (S) Pte Ltd

JOil is a Singapore based company with a goal to establish agricultural projects using plant sciences & processing technologies as its core strengths. JOil commenced its activities with focus on Jatropha. In addition to providing planting materials and agronomy practices, JOil is also working on production of high value-added products for both energy and non-energy applications. Over a period of 11 years the company and its partner and shareholder, Temasek Life Sciences Laboratory have established a set of enabling technologies aimed at regenerating and transforming *Jatropha curcas* for commercial cultivation. With significant potential to provide technically superior components for important groups of high value industrial products, Jatropha is considered as a futuristic sustainable option for production of bio-based products for both energy and non-energy applications. JOil, backed by a group of powerful international industrial shareholders, including Temasek and Tata, is a technology-led organization. JOil currently has operations and commercial links in Asia, Europe and Africa and plans to use them to develop trade links among these regions. JOil is an active member of Roundtable for Sustainable Biomaterials, and is committed to ensure sustainability.

Company and Management

JOil has been a pioneer in Jatropha development, the initial phase of the Jatropha related R&D programme that is today at the heart of JOil's activities was commenced in May 2006 and involved 6 research groups within Temasek Life Sciences Laboratory (TLL) involving more than 25 researchers. When JOil was formed in 2008, it expanded its development and operations activities in India and Indonesia. Since then it has made substantial and tangible progress by expanding in the West African region through its pilot Jatropha plantation, and in Europe through its strategic partnership with Agroils Technologies Spa.

Management

JOil is organised as a management team reporting to a Board comprising representatives from JOil's shareholders. The management team guides a technical team of 7 doctorate level scientists. The combined scientific and management resource is supported by a Scientific Research Committee comprising senior research scientists, & industrial scientists. The senior management team includes:

Srinivasan Sriram, Chief Operating Officer

An MBA from a renowned Indian University and has about 27 years of in-depth experience in finance, strategy and management. He worked with the Tata Group in India for more than 14 years and was seconded to JOil in September 2009 as GM (Strategy & Marketing). He took up the role as Chief Financial Officer at JOil and played a key role in formulating strategic tie-ups and business initiatives. Before moving to JOil, Sriram was heading the biofuels division of Tata Chemicals Ltd., and was instrumental in setting up various agro-climatic research sites for Jatropha in India and Africa. He also played a lead role in setting up a bioethanol plant in India and in participating in various international projects in Mozambique and Brazil. He is also a board director for Roundtable on Sustainable Biomaterials. At JOil, Sriram was instrumental in developing the value chain approach, setting up India operations and M&A deals including Monfori, Smart Oil and Agroils. He is currently the Chief Operating Officer in charge of strategy, finance and operations.

Dr. Srinivasan Ramachandran, Chief Technology Officer and Director for JOil India and JOil Africa

Obtained his PhD in Biochemistry with Plant Molecular Biology as specialization from University of Idaho, USA. In 1993, he joined Prof Nam Hai Chua's group at the Institute of Molecular and Cell Biology, later at the Institute of Molecular Agrobiology, Singapore. He headed the group of Rice Functional Genomics at Institute of Molecular Biology, later at Temasek Life Sciences Laboratory. He also led a group at the Institute of Genetics and Developmental Biology (IGDB), Chinese Academy of Sciences, Beijing, China (2003-2008) and Center for Bioenergy Plants, at Institute of Botany, Chinese Academy of Sciences, Beijing, China (2007-2011). He has more than 60 peer reviewed publications and several patents to his credit. In addition to leading the technology team, he was instrumental in setting up JOil India operations, and supervising its field trials and seed production. He is also leading JOil's African projects. He is also an Adjunct Associate Professor at Nanyang Technological Institute, Singapore.

Vartika Gupta, Senior Manager - Finance & Strategy

A Bachelors in Chemical Engineering, MBA in Finance and Master in Financial Engineering (NUS). She has over 10 years of post-MBA work experience in the areas of finance, strategy and business planning. Her notable contributions include developing long term strategic plans, converting them into actionable business plans and tracking business performance. She brings with her strong financial modelling skills, which have been deployed, in M&A and business development activities. Prior to her current role in JOil, Vartika worked in the Investment management and Chemicals sectors. She has contributed to developing value chain approach, business modelling, M&A deals and strategic review of JOil business.

Dr. Kins Varghese, Director for JOil India and JOil Ghana

A PhD in Agronomy, an MBA from IGNOU and MIPL (Master of Intellectual Property Law). He has over 15 years of experience in the agronomy of various crops. He started work on Jatropha since 2005 under Mission New Energy's 80,000 ha Jatropha project in India and gained extensive knowledge and skills in managing multi-location Jatropha plantations, especially contract farming and experimental trials across India and in Africa. As part of the team he was instrumental in the development of Package of Practices for Jatropha cultivation under various agro-climatic conditions. In addition to daily management of JOil India operations, he is also managing JOil's African operations. He has 21 research papers, 11 popular articles and a Book on Seed Technology to his credit.

Dr. Yi Chengxin, Chief Breeder

A PhD in Plant Genetics and Breeding from Nanjing Agriculture University, China. He has over 23 years of experience in crop genetics& breeding, large-scale plantations and experience in molecular marker assisted selection and transgenic breeding in cotton, rice and Jatropha. He has worked on Jatropha since 2006 on its genomics, genetics and breeding. Being a crop geneticist & breeding expert with strong knowledge and experience in agronomy and field trials, he is leading JOil's Jatropha breeding and agronomic research. He made significant contribution to the pipeline of new Jatropha varieties, especially hybrid seed varieties.

Dr. Hong Yan, Consultant

Has a background in biological science training (PhD, Chinese Academy of Medical Sciences, 1989) and business studies (MBA, National University of Singapore, 2001). Since 1998, he conducted independent research in the Institute of Molecular

Agrobiology (later in Temasek Life Sciences Laboratory) on biotech crop development, forestry biotechnology, herbal medicine, bioenergy plants and new technology development. He started working on Jatropha since 2006 and was instrumental in setting up JOil's Breeding program. He led the R & D team in developing the pipeline of new Jatropha varieties and new processing technologies, applying and conducting the global first GM Jatropha field trial and securing plant breeder certificates for JOil elite varieties. Presently he is a faculty at the School of Biological Studies, Nanyang Technological University (NTU) and is also a member of Singapore Genetic Modification Advisory Committee and is helping in JOil's varietal development programs especially GM.

Shareholders

JOil has an impressive shareholder list. Included amongst its largest and most influential shareholders are the three organizations detailed below.

Temasek Group & Temasek Life Sciences Laboratory (TLL), a beneficiary of Temasek Trust, is a non-profit organization established in 2002 to undertake frontier research in molecular biology and genetics utilizing a broad range of model organisms. Affiliated to both the National University of Singapore and Nanyang Technological University, TLL has some 220 researchers and is working to develop the biotechnology industry in Singapore through collaborations and joint research ventures with local & international partners. Temasek Life Sciences Ventures Pte Ltd is an investment holding company whose mission is to commercialize life science technologies and intellectual property including those developed by Temasek Life Sciences Laboratory Ltd (TLL).

Tata Chemicals Limited is a global company, which has interests in businesses that focus on LIFE: Living, Industry and Farm Essentials. The company is the world's second largest producer of soda ash with manufacturing facilities in Asia, Europe, Africa and North America. Tata's industry essentials product range provides key ingredients to some of the world's largest manufacturers of glass, detergents and other industrial products. With its farm essentials portfolio Tata Chemicals has emerged as a supplier of crop nutrients in India. The Tata Chemicals Innovation Centre is focused on research & development in the fields of nanotechnology and biotechnology, and the company's Centre for Agri-Solutions & Technology provides advice on farming and crop nutrition practices. Tata Chemicals has a market capitalisation of $2.7bn.

Toyota Tsusho Corporation is the product of a merger, in April 2006, between the Toyota automotive business and Tomen, which had developed a wide range of business and customers outside the automotive sector. The new Toyota Tsusho group combines a global network and trading activity underpinned by a successful manufacturing culture. Listed on the Tokyo Stock Exchange it has a market capitalisation of some $7.6bn.

Crop Improvement – from Generation 1 to Generation 4 Varieties and Hybrids

If there was one major reason for the failure of the Jatropha projects in the last decade, it can be certainly attributed to the use of unproven wild types of Jatropha for establishing commercial scale projects. This, combined with lack of wellresearched agronomy practices, any understanding of Jatropha farming systems, nor an appreciation of how to unlock value in downstream products, led Jatropha to become a victim of misleading promotions and unjustified projections. JOil, through its research, has evolved elite varieties and hybrids with desirable commercial traits of higher yields, short gestation period, pest & disease tolerance, oil content etc. JOil is putting its expertise in biotechnology and genetic engineering, to use in the achievement of significant increases in desirable plant traits.

Foreseeing the need for proven high yielding varieties, JOil in 2008, commenced its scientific and structured Jatropha breeding program, which resulted in the evolution of **Generation 1 (GEN 1)** varieties of Jatropha, **JO S1 and JO S2**. These elite varieties were evolved from a mix of promising accessions collected from across the globe representing a wide range of agro climatic conditions. The yield potential of these varieties is in the range of 4 – 5 tonnes per ha. Such varieties can be used to develop economically viable, large scale Jatropha projects. JOil's pilot project in Ghana is being developed using these varieties.

Sustained efforts in research and breeding resulted in the evolution of high yielding intra specific hybrids representing the **Generation 2 (GEN 2)** in the Jatropha business. The hybrids were characterised by their abundant and early flowering pattern and 20% – 30% higher oil productivity as compared to the Generation 1 Jatropha varieties. Such varieties provide greater IP protection and higher economic returns. JOil has conducted field trials of these varieties in India and Ghana and plans to use them in the development of its first large scale commercial farm in Ghana.

Generation 3 (GEN 3) Jatropha varieties were the outcome of interspecific breeding program. These varieties are suitable for high density planting. The plants are small statured, amenable for growing as a short duration crop and adaptable to be grown as rain fed crop in a wide range of agro climatic geographies.

Generation 4 (GEN 4) varieties were the outcome of its high-end genetic engineering and research program. JOil in association with TLL has developed a Genetically Modified (GM) Jatropha with 75 % Oleic acid, as compared with the 45 % Oleic acid content in other genotypes. The higher Oleic acid content gives a better balance between the cold flow property and oxidation stability of the fuel derived. Genetic research is also being conducted on specific traits of *Jatropha curcas* including virus resistance, higher seed oil content, drought tolerance, and a reduced presence of curcin & phorbol esters. Such varieties will help produce high quality biodiesel and bio lubricants. JOil is the first company to conduct a GM Jatropha (high oleic acid) field trial. It has established a purpose built 1.4 ha site in a well separated island, off the coast of Singapore.

Value Chain Maximisation

JOil along with its partner Agroils has been working on development of high value Jatropha products and on the creation of market for such products. Through patented processing technologies, the companies have developed high value products from Jatropha seeds that can be used for non-energy applications such as industrial chemicals, synthesis of natural wax, bio-glue, bio-fertilizer and bio-pesticides, in addition to the conventional energy applications of Jatropha such as its use as biodiesel and biojet fuel. The detoxified Jatropha kernel meal could be a potential source of protein in animal feed formulations. The major products coming out of Jatropha bio refinery include:

Clarified Oil, can be used for production of bio-lubricants, biojet fuel, printing inks, natural wax candles and bioplastics

Jatropha protein can be used for production of formaldehyde free bio-adhesive with a market in wood industry (particle board, plywood, MDF). Detoxified kernel meal has the potential to be used as a protein source catering to the animal feed industry.

Other components can be used for production of bio fertilizers, bio pesticides, paper, biogas, pharmaceuticals etc.

The choice of right mix of value added products in accordance to the market demand and price promises a much higher value generation for large scale Jatropha projects ensuring sustainability and profitability.

Pilot Project in Ghana

JOil has developed a pilot Jatropha plantation in Ghana. The project serves as a platform to demonstrate a proof of concept for entire Jatropha value chain with practical demonstration of commercialization of all Jatropha products and by products including oil, kernel meal and biomass.

Ghana Project

Ghana's agro-climate and land availability promise significant potential to establish commercial scale Jatropha projects. JOil has secured access to more than 4,500 ha of suitable land in the Brong-Ahafo region in Ghana, for the establishment of a rainfed Jatropha plantation with intercrops. By end July 2017, 300 ha of land had been planted with elite varieties of Jatropha and 55 ha with food crops including Cowpea, Sesame, Sunflower, Soybean and Groundnut. The plantation has yielded 0.6-ton dry seed /hectare in the 1st year of planting; and is expected to yield 4-5 tons/ ha at maturity in its fifth year.

The pilot project has been setup in compliance with Ghana Environmental Protection Agency. An Environmental Impact Assessment and Environmental Management Plan (EMP) was submitted after receiving an Environmental Permit from the Agency. Based on the above, an Environmental Certificate was obtained from the Agency.

A percentage of the seeds produced from this planation have been processed at Agroils' pilot processing plant in Italy. The products (in tens of tons) have been sold to industrial players in Italy. High quality clarified oil has been sold to bio-lubricant manufacturers and Jatropha protein based adhesive have been sold to particle board manufacturers.

Ghana Project Expansion

JOil plans to expand this project into its first commercial scale project by planting up to 20,000 ha by 2020. The plantation will include both proprietary farming and contract farming, using an intercropping model. A processing unit will also be set up in Ghana to derive various Jatropha products both for local and international markets. The project will be developed by complying with the applicable International standards on Environmental and Social Sustainability.

In addition to general development of the community in the area, the project will also generate significant direct and indirect employment opportunities for local people in the region as well as foster the sustainable development of key industrial sectors both at regional and at national level. It will also generate business opportunity for local farmer community through contract farming, thus giving a guaranteed market outlet and reduced uncertainty regarding product price. The project will help to promote social and economic development of the community.

The project would address the increasing demand for non-energy products such as formaldehyde-free protein-based adhesives for wood sector (i.e. plywood), protein enriched fish meal for aquaculture sector, and natural compounds to fight pests and disease transmitting vectors. The products and by products can also create an export market in the EU such as oil as a feedstock for bio-lubricants, protein based bio-glue and bio-pesticides. It would also cater to energy requirements of the region – for biodiesel and for electricity using oil and biomass, thus addressing the needs of different stakeholders.

Hardman Agribusiness Comment

JOil was an early entrant to Jatropha crop science, in which it has developed a leading position with rigorous and wide-ranging research, well-documented breeding achievements, and persistence in the face of the significant challenges to the proposition of Jatropha becoming an important commercial crop. Throughout its history, JOil has been underpinned by the financial and technical support of its far-sighted industrial and science based investors.

JOil is now seeking to demonstrate the commercial feasibility of the Jatropha value chain with the initiation of a significant demonstration farm in Ghana, and active support for the development of downstream industrial applications for Jatropha fractions, as evidenced by its participation in Agroils SpA.

If successful in all these endeavours, JOil will not only have been a pioneer in the development of enabling technologies for the development of Jatropha as a commercial species, it will also have led the way in the commercialisation of Jatropha cultivation and its adoption by big industry as a preferred precursor for high value industrial applications.

Agroils Technologies S.p.A.

The Italian company, Agroils Technologies S.p.A. (Agroils) has developed a range of proprietary and environmentally sensitive, technologies for processing bio-oils and bio-materials, (including Jatropha), for technologically superior fractions with application in the manufacture of high-value industrial products including, bio-adhesive materials, industrial lubricants, animal nutrition, pharmaceuticals and bio-pesticides. The company's primary focus is on crops which are:

- drought resilient;
- oleaginous;
- primarily non-food.

Partnership with JOil Pte Ltd

In November 2015, Agroils and JOil entered into a strategic partnership, with JOil taking a 35% equity stake in Agroils. JOil is now supplying Jatropha products to the Agroils ABR platform, evidencing the development of an integrated Jatropha supply and value chain.

Business Model

In 2014 Agroils established a 1,000 tons/year demonstration plant in Florence, for the extraction of plant oils and proteins. Agroils refers to this facility as the 'Aqueous Bio-Refinery' (ABR). The company asserts that the ABR technology platform provides a more cost-effective process for the recovery of plant oils and proteins (than competing technologies), while being both safer in use and more environmental friendly. Agroils advises that the ABR technology process is suitable for multi-feedstocks, it is modular in design, and easily scalable.

ABR-platform produces intermediate products for MWFs & Bioresins

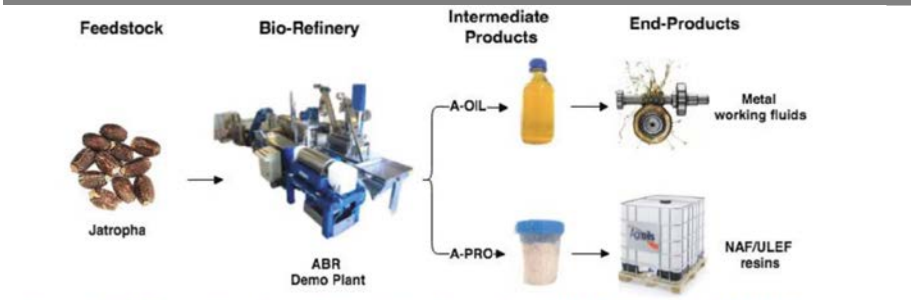


Figure 2 : ABR-platform used to produce industrial grade intermediate products for Metal Working Fluids and NAF/ULEF resins.

Source: Agroils Technologies

The company's business model is focused on the generation of revenues from the supply of bio-components for use in the manufacture of industrial lubricants and adhesives for the wood panel sector. Agroils reports that it has concluded MoUs with:

- two of the largest wood producers in Italy: Panguaneta and Gruppo Saviola;
- The German bio-lubricant producers DAW-AEROCIT and Foundry Alfe Chem.

The company notes that it has signed a Letter of Intent with Vigolungo (Italy's second largest producer of plywood).

With a focus on sustainability, Agroils is also involved with a diverse range of projects including:

- an EU funded renewable Jatropha Electricity System (JES) production project, based on the use of Jatropha oil, in an off-grid village (Mankim) in Cameroun;
- a bio-diesel production project from waste vegetable oils in Dominican Republic;
- an afforestation and carbon sink project on degraded land in Senegal.

Resolute Genetics, LLC

Resolute Genetics LLC (“Resogen”) was formed in late 2016 by three senior members of the former SGB’s management team (President & Chief Operating Officer - Miguel Motta, Chief Scientist - Robert Schmidt, Ph.D., and Michael Pereira - Chief Agricultural Operations), and Richard Rotter, a plant breeder in Guatemala. In addition to an in depth understanding of *Jatropha curcas*, Resogen’s team has deep expertise across the genetics, breeding and biology of the species. The team is focused on the development of novel crops for the production of sustainable, high-value products, and the utilization of redundant farmland.

In December 2016, Resogen acquired the entirety of SGB’s germplasm assets, including accession families, FO (female only) and Male (monoecious) inbred lines, and hybrid seed stocks, plus all of SGB’s IP.

Commercial Strategy

Resogen argues that although the traditional markets for Jatropha products, as a source of renewable energy (biodiesel, jet fuel and biomass to energy conversions), have all but evaporated in the face of crude oil trading below $65 bbl, there is a significant commercial future for Jatropha derived products in high value industrial applications. To realize these opportunities, Resogen is working with a number of development partners, including:

- Algenesis Materials: formulating Jatropha oil into polyols for a number of potential “green” polyurethane-based applications.
- The BioDiscovery Institute at the University of North Texas: to demonstrate the economic potential of extracting a renewable precursor for carbon fiber generation from the seed coat of Jatropha.
- Engaging potential partners for trialling Jatropha oil for functionality as a biopesticide

Research & Development Programme

Resogen’s current research and development activities include:

1. a breeding evaluation in Guatemala of over 500 Jatropha hybrids derived from well-inbred female (F4 and F5 inbred lines) and male parental lines (F5 to F7 inbred lines).
2. the top performing 5% will be:

- reseeded in 2018 in a randomized, replicated trial and scored against top yielding hybrids from SGB’s prior breeding efforts
- further developed for suitability as an annual crop which will require that such hybrids can achieve economic yields in temperate climates (Resogen is targeting the southern U.S. states)

- this will require performance in high density planting formations using the early flowering hybrids already developed.

Hardman Agribusiness Comment

Resogen carries forward the research launched by the former SGB Inc. The team has a reputation for divergent development strategies and a focus on the commercialisation of Jatropha. While the remaining European names in the Jatropha crop science sector have maintained a significant focus on the crop's development for marginal agricultural environments and smallholder farming systems, SGB/Resogen's focus evolved to concentrate on the opportunity for Jatropha to have commercial importance for 'big-farming'.

Future Energy Ltd (Uganda)

Future-Energy Ltd (F-EL) is an independent processor of Jatropha kernels supplied by some 40,000 Uganda out-growers in the North West of the country. Established in 2007 by Norwegian and Ugandan nationals, F-EL has developed into an important producer of sustainable Jatropha products for local consumption, including Crude Jatropha Oil (CJO) for the manufacture of biodiesel, and 'Biochar' for use as biofuel, and also for production of organic fertilizer.

The out-grower supply chain is expected to provide sufficient feedstock for F-EL to produce 1,400 metric tons of CJO in 2018. F-EL has worked with its out-grower suppliers to improve planting materials and cultivation practices, thus supporting annual yields of up 12 kg of seeds per tree at maturity. Planting densities will vary according to the pattern of mixed-crop farming practiced by each out-grower.

While Uganda is F-EL's primary market focus, the company advises European buyers would be willing to off-take the F-EL's entire production of CJO. Demand for biodiesel is strong in the region where F-EL's operations are based, and the outlook for local consumption may be strengthened further if Uganda implements a 20% blending mandate in 2018. Currently, F-EL is achieving a minimum price of USD 1 per liter of biodiesel and USD 0.1 per kg of briquettes/pellets (organic fertilizer option exists). F-EL has initiated the process of registering and trading carbon credits; the company indicates that the utilization of carbon credits may have a value in the region of USD 1,5 million.

A Ugandan Business

The F-EL operations are staffed by a mix of local people, Norwegians and Danes. Two Ugandan staff are responsible for day to day operations and local management, while the marketing team and financial management, comprises individuals from Uganda (1), Norway (4) and Denmark (1). This team has international experience within finance, oil and gas, sales, marketing and renewable energy.

Supportive Investors

To date F-EL has received total investments of some $1.68m, comprising

- $670,000 - research and consultancy from universities
- $310,000 - Norwegian government and research centres
- $400,000 – shareholder loan.

New Production Technologies

Over the last year the company has been testing various new production systems for recovering Jatropha oil and for commercializing biomass from the oil pressing process. With the test phase now completed, the operation is entering commercial phase. To this end a production site has been acquired with electricity, water, and buildings in place. All approvals with the authorities have been secured and the venture is supported by a research farm of 300 acres, to encourage and promulgate best practice amongst the out-grower supply base.

Biochar Production

Source: Future Energy Ltd (Uganda)

Social and Value Chain Development

The F-EL operations represent a 'joined-up' Jatropha value chain. The payments received for harvest kernels provide an additional income stream for regional farmers, commercialization of the sustainable farming practice of mixed-cropping with Jatropha via carbon credits and the production of CJO for biodiesel, manufacture of soap, lamp oil, biopesticide, mosquito repellent, and Biochar.

F-EL's management believes the production of CJO could be scaled up to as much as 8,000 mt per annum with modest additional investment. At these volumes, the production would be sufficient to support the production of polyols for polyurethane production, and the manufacture in country of bio-degradable polyurethane footwear. This would represent a first for Jatropha as an end-to-end value chain from farm to consumer via cultivation and harvesting, to processing, sub-manufacture, and ultimately consumer goods manufacture and distribution. For regional African economies and livelihoods, this offers a potentially higher value-added opportunity than the manufacture of biodiesel.

Hardman Agribusiness Comment

If, as proposed, F-EL can produce 8,000 mt of CJO annually, it will be by far, the largest single producer of CJO in the world, according to our data. The F-EL model will validate the theory that Jatropha is a crop best farmed by smallholders for the supply of dry seed to industrial expeller units. However, from our perspective, it will be the availability of industrial volumes of the commodity (albeit small), that will provide the opportunity, for Jatropha commodities to establish commercial value chains.

Appendix - *Jatropha Curcas*

Jatropha curcas Linn. (referred to hereinafter as Jatropha), or physic nut as it is commonly known in many parts of the world, was described by Carl Linnaeus in 1753 as a member of the Euphorbiaceae family – a family known for their milky white sap and phytotoxins. Jatropha is a perennial, deciduous, stem-succulent shrub or small tree with growth up to 5 metres which is able to remain productive for up to 50 years. It is considered to be native to Central America which has a sub-tropical humid climate with no marked winter; even the coldest month averages above 18 °C, with summers of 27 to 28 °. Rainfall at 1,100 to 2,000 mm is high and regular. The Central American region is however characterised by a marked dry season of several months from which Jatropha has evolved its capacity to withstand long dry spells. Fruit yields are highly dependent on climatic and soil conditions. Under conditions which are highly suitable to the plant, it has been reported to yield between 2 to 5 tonnes of seed per ha per year, producing up to 2 mt in its first year. A remarkably deep rooting plant, it is a useful species in soil remediation, bringing deep mineral fertility to the soil via leaf litter.

The plant produces bunches of 2-3 cm diameter fruits, which contain usually 3, sometimes 4, black 1 cm long seeds or grains of approximately 0.6-0.9gms each. The grains have thick black hulls protecting the grain kernels. The kernels are rich in oil and protein. After processing, one metric tonne (mt) of Jatropha grain typically results in 250kg - 350 kg of oil, 350-400 kg of high energy hulls (35% shell is most typical in commercial lines) and the balance in a Jatropha kernel meal containing circa 65% protein. Crude Jatropha oil (CJO) can be extracted from Jatropha seeds either hydraulically using a press, or chemically using solvents (Heller, 1996). Chemical extraction is reported to permit up to 40% oil extraction rate (OER), while mechanical pressing typically achieves 24%-28% OER.

The fatty acid composition of CJO contains four important fatty acids: palmitic, stearic, oleic and linoleic acid. However, the seeds contain a toxic protein called curcin (lectin) and diterpene esters (phorbol esters), both of which are harmful to humans and most other animals. Curcin hinders protein synthesis in vitro (Stirpe et al. 1976) and is quite similar in structure to ricin (however ricin is 1,000x more toxic) which is the toxic protein of the castor bean (also a member of the Euphorbiaceae genus), to which Jatropha is related.

According to Brittaine & Lutaladio, (Integrated Crop Management Vol.8-2010) there are some 170-known species of Jatropha, and these are predominantly associated with Central America. Scientific literature notes three particular varieties:

- Nicaraguan – a large species but a poor producer of fruits;
- Cape Verdean – commonly found throughout Africa & Asia;
- Mexican – noted for lower toxicity & non-toxic varieties.

Jatropha can be planted as a commercial crop in a band up to 25 degrees north and south of the Equator on a range of soil types. Planters we have spoken to confirm that Jatropha does best in deeper free draining soils with annual rainfall of more than 1,000mm pa. The crop is very sensitive to frost and periods of continuous rain. Crop performance, as with most plants, is significantly influenced by the availability of sunlight, warmth, water, and soil nutrients in the growth site environment. Altitude appears to be an important determinant, affecting the maximum, minimum and mean temperatures and surrounding humidity. Jatropha can grow at altitudes of up to 2,000m on the Equator, but needs intensive management to yield useful volumes of fruit. In its native region it is thought to have occurred at altitudes below 500 metres.

Climate Preference

Optimum temperatures for Jatropha are generally considered to be between 20 degrees – 32 degrees Celsius. Very high temperatures are thought to depress yields as flowers can be damaged by extreme temperatures and thus fail to develop seeds; this has been the experience of some farms in Northern India where temperatures exceed 38 degrees Celsius. It is important that night temperatures do not fall below 15 degrees if the plant is to avoid stress and this confirms the plant's preference for lower altitudes. Jatropha has shown to be well adapted to high light intensity (Baumgaart, 2007, cited Jongschaap, 2007). Optimum rainfall for seed production is thought to be in the range of 1,000mm to 1,500mm, but high yields on trial sites have been reported in very high rainfall areas (2300mm) in Asia. Similarly, the plant is reported to perform well in drier regions 400mm-800mm where irrigation is provided. We have received reports of 4 mt / dry seed / ha harvested on selected wild stock in various locations in South America (Northern Argentina, Paraguay, northern Minas Gerais) in a bimodal 800mm rainfall environment and without irrigation. (Cazenave Y Asocciados SA). Water conservation techniques including use of water capture pits, slanted ditches, mulching and provision of ground cover plants might all be useful in lower rainfall zones.

Research has indicated that in very high rainfall areas Jatropha is vulnerable to fungal attack (Foidl, 1996, cited Achten 2008) and perhaps for this reason the plant is not found in the more humid regions of its native Central America. Indonesian growers have also reported to us that the plant tends to greater vegetative growth and lower fruit yields, in high rainfall tropical environments, but this may have as much to do with the planting material used as it does with climate. Evidence from existing cultivations demonstrates that commercial cultivation benefits from bimodal rainfall patterns; rainfall induces flowering and thus in areas of unimodal rainfall the plant flowers continuously which has implications for management of harvesting and crop maintenance. A 3 to 4-month dry season, as is typical of West Africa and parts of Asia, provides the plant with a period of dormancy which allows for tree & field maintenance, and which then encourages more concentrated harvesting periods. While Jatropha will survive in semi-arid conditions it is generally observed that it requires at least 600mm to flower and set fruit.

Soil Preference

Research indicates that Jatropha is happiest in aerated loam & sandy soils of at least 45 cm in depth (Gout, 2006). Heavy clay is not deemed suitable for the plant because of its ability to deform root development and its tendency for water-logging, which renders Jatropha vulnerable to fungal attack. While we have seen the crop growing relatively successfully in clay soils, these have been terraced sites and drained to avoid water-logging. Soil pH is deemed to be best in the range 6.0-8.5 (FACT, 2007). Jatropha has a deep penetrating tap root that has been measured at up to 1.4 metres (Krishnamurthy et al, ICRISAT, January 2012) and otherwise reported at up to 5 metres in the plant's native region (Foidl et al, Bioresour Technol 1996). This is likely to reflect the different responses to the plant to different soil structure conditions, with deep penetrable soils its preferred environment.

Pest & Disease

Jatropha attracts a substantial insect and disease burden in many African locations, and this is especially burdensome for the plant when it is stressed; low rainfall environments therefore carry a double danger for plant performance. Systemic treatment of the seed and young plants, regular field monitoring / scouting and identification of infestation early are necessary plantation procedures along with an appropriate integrated pest management system.

Under scaled monoculture cultivation it has been found that pest and disease control is important. Good farming practices, including the encouragement of natural predators of Jatropha related pests, plus the use of chemical products, represent the main strategies for crop protection, but selective breeding also has an important role. The diverse geographies across which Jatropha is cultivated, will produce different resistances, and accordingly, will imply the necessity for regionally specific crop management strategies. Accordingly, a focus on localization, forms a key focus for Jatropha breeders and developers.

A Competitive Agricultural Species

Compared with globally important tree crops such as palm oil and natural rubber, both supported by circa 100 years of applied crop science, Jatropha is still in an early phase of development. Yet the species lends itself to accelerated development due to the ease of sexual reproduction and its short generation time. Despite being a woody perennial species, Jatropha can finish one round of flowering and seed setting in as short as 6-7 months (seed to seed), especially in the humid tropics or in irrigated environments. It is now technically possible to achieve two improved breeding steps within a 12- month period.

Developers have noted also that some cultivars demonstrate a significant proportion of their yield potential in year one, although this will not be all that may be possible at peak maturity. It has also been noted that age of maturity in some new lines has been shortening, with optimum cropping now considered to be possible in years 3-4. This possibility of early detection of potential productivity helps accelerate development programmes, although the seasonality of fruiting remains a retarding factor.

Whereas last century Jatropha required 4-5 years and more to reach full productivity, some breeders report that certain modern hybrids have been shown to achieve almost full productivity between years 1 and 2 under irrigation. Resogen Inc (formerly SGB) reported in 2015, that its most advanced JMax Hybrids produced first year yields of 7 mt/ha during trials which are on a par with the yields of First Generation Hybrids at Year 4 (6.0mt/ha), evidencing an apparent acceleration to maturity in these hybrids.

Jatropha's markedly shorter generation cycle compared to African oil palm (*E. guineensis*) or natural rubber (*H. brasiliensis*), can be viewed as a commercial and technical advantage. Jatropha crop scientists are now working on further shortening the time to productive maturity by focused breeding, in order to develop a commercial annual cropping variety. There are now three distinct development routes for the crop:

1. As a perennial tree crop
2. A short rotation shrub crop of 2-3 years
3. As an annual crop with very high planting densities.

Perennial Tree Crop

A breeding & development cycle for the introduction of a new commercial cultivar may take just 2.5-3.0 years. Ultimately however, the productive and economic profile of these perennial cultivars can only be fully understood over a 5 to 10-year period, embracing both the plant's immature and mature years. Only a long period of monitoring the plant (under diverse cultivation conditions) will provide the fullest understanding of its yield profile, its resistance to cropping induced biotic stress, climate variability and disease & pest predation. A significant hardy tree requiring few inputs would of course have a longer maturation period but for low density plantations, perhaps with intercropping with other cash crops, such a variety would suit the model of sustainable Jatropha in environments deemed not suitable for food crops.

Short Rotation Crop

A small sized shrub suitable for high density plantation planting would require more inputs to produce commercial quantities of seeds in its early years and with development focusing on its suitability for mechanical harvesting and maintenance.

Annual Crop

The capacity of some lines to produce significant volumes of seeds in their first year is a trait that is being pursued as one of the principal development paths for the crop. Crop science specialists like JOil and Resogen, are seeking to annualise Jatropha, with breeding for specific plant morphology and mechanization of the crop. Annual varieties would be planted in high density formations for end of season cropping, suiting farming patterns in temperate climates, or locations characterised by marked dry and wet seasons. A Jatropha crop that could be produced in the wet season and then harvested in the dry season with the remaining plants then being gathered for use as biomass, would have considerable application. JOil has conducted trials with suitable varieties in both Singapore and India.

High density planting (ranging from 5,000 to 30,000 stands per ha), particularly via direct seeding, has the potential for economic production of commercial volumes of seed per hectare within the annual cycle of a farm. As the crop would be rotated annually, space and light competition from high density concentrations would cease to be a problem. This would call for a shorter stature and limited canopy. Such a development would both extend the range of the crop to temperate and continental climate zones (from which it would otherwise be excluded due to its vulnerability to night time temperatures much below 7 degrees Celsius) and would reduce the commercial risks for farmers experimenting with the crop. Indeed, the experience of the Jatropha crop science sector with the plant's proven capacity for very short cycle regeneration has the potential to disrupt much of the earlier thinking about the cultivation of the species, and to provide solutions to economic concerns about the management of Jatropha plantations including specifically harvesting and pruning.

Notes

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