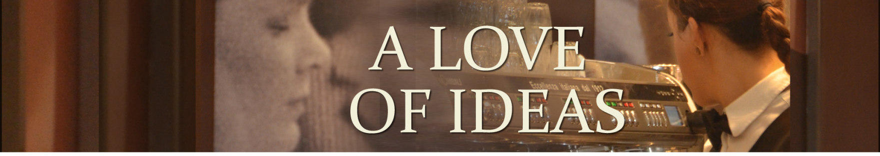

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The contrasting need for food and biofuel: Can we afford biofuel?

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OUR WORLD in the second decade of the 21st century is characterised by extensive growth of the human population (7.2 billion humans in 2014, with one billion extra expected in the next 12 years), and a parallel increase in the use of fossil fuels such as crude oil, natural gas and coal. These present trends cannot continue without resulting in grave implications affecting the global quality of life. Numerous speculations exist regarding future scenarios.

Population growth and energy demand are clearly interacting. Increased carbon dioxide (CO_2) levels, caused by oxidation of fossil fuel, together with other greenhouse gases (GHG) such as methane (CH_4) and nitrous oxide (N_20) appear to be causing a global temperature increase. This results in increased fluctuations of climate (storms, rain, drought, heat), thereby increasing the frequencies of regional crop failures. Globally, opinions are divided on the significance, severity and human-caused mechanisms of such climate change. The actual causes do not matter because fundamentally we must act to lower fossil energy usage, as resources are being depleted and natural replacement of fossil fuels such as crude oil does not occur.

Direct destruction of agricultural land and agriculture-related infrastructure also occurs globally, caused by increased salinity, urban development and soil nutrient exhaustion. Sadly, deforestation occurring on a large scale in Indonesia and Brazil actually adds to available agricultural land, but often of short-lived fertility, accompanied by loss of CO_2 sequestration and loss of species diversity. At the same time, an increasing human population (now over 7 billion, and predicted to reach over 9.6 billion persons in 36 years) requires living space; as cities expand, agricultural land in surrounding areas is being absorbed either as housing space, commercial districts, or even recreational areas such as golf courses.

In parallel, many global areas in agricultural food production are challenged by environmental deterioration; for example, excessive irrigation increases salinity levels, and over-farming with little fertiliser supplementation causes yield drop. With predicted stresses caused by global climate change, such loss of useable land will increase in the next few decades.

Agricultural productivity per hectare needs to expand to keep up with progressive reduction of productive land. Over the past 100 years, humanity has shown great ingenuity to do just that. Development of new technology (for example, tractors, harvesters, and irrigation rigs) progressed in concert with genetic advances brought about by the new discoveries of Gregor Mendel and other geneticists. Chromosomes and DNA were discovered, as were DNA profiling, gene transfer, and RNA expression analysis. Humanity has accumulated a large database on agricultural (and other) plants, but little in these data files helps daily production or even lowers costs.

This is highlighted by the now non-functional 'Green Revolution' of the last half-century, which introduced crop plants with increased 'Harvest Index' (seed versus total organism mass), new planting regimes, industrial fertilisers at low cost, and plants with induced or selected disease resistance or other relevant agronomic traits. Since the invention of the Haber-Bosch process, which combines atmospheric nitrogen

(N_2) gas and costly to synthesise hydrogen (H_2) gas under high pressure and temperature (about 450°C) to form ammonia (NH_3), agriculture had a ready supply of crop-limiting nitrogen supply. Indeed, most current crops receive an industrial fertiliser made via the Haber-Bosch process, using natural gas as fossil fuel energy source. Such fertiliser is often in the form of nitrate (NO_3–), urea, or liquid ammonia. This focus on the necessity of industrial fertilisers leads to the production of greenhouse gases (GHG) and increased operational costs.

The genetic improvement of crop plants faces a problem. During the early days of the Green Revolution, by selecting among pre-existing 'landraces' or cultivars it was possible to find the one best suited for a specific environment/growth condition. Subsequently, induced mutations were utilised, where seeds treated with a mutagenic chemical agent or radiation were advanced to the second generation, which allows the selection of homozygous mutant alleles, and hopefully an improved crop characteristic. Likewise, classical plant breeding, utilising hybrids produced by sexual crosses or polyploidisation, advanced the spectrum of seed lines yielding better and more reliably. Tremendous advances were achieved.

However, if one looks at the annual yield increase of major crops like rice, wheat, corn, and soybean over the past four to five decades, one sees increases of about 2% per annum in the 1980s that have now decreased to less than 1%. The reasons are clear: plant genetics is limited in the amount of allelic variation that can be combined to have heterosis (hybrid vigour) for improved yield.

Since the 1980s there is, however, a new technology that has promise for crop productivity. This is called 'genetic engineering' or 'recombinant DNA technology', involving the stable introduction of a new gene, from whatever origin, into the crop's genome. Even today this insertion process is random and still requires broad multiplicity and subsequent phenotypic selection. Effective advances have occurred, combining the power of major seed companies and academia. Genetically modified organisms (GMOs) have penetrated deeply into global markets, despite some public opposition and mistrust. For example, Roundup-Ready (herbicide tolerant) and BT (*Bacillus thuringiensis*) toxin (an insecticide) modified plants such as cotton, potato, corn, soybean and canola (to name just a few) are broadly established in agriculture. About 99% of Canadian canola is a GMO (notably without apparent international trade implications).

However, the costs of such crops are high and yield improvement is limited. For years, Roundup-Ready soybeans had a slightly lower yield than their parents. Farmers cultivated it for 'love of modernity', or apparent fear of crop losses due to weeds. At least today these limitations have been removed.

While the spread of herbicide and insecticide GMO technology is welcome and impressive, the development of GMO crops with improved yield properties has been slow. Presently, there are tests on plants with improved water-use efficiency (WUI), fatty acid content (especially omega 3 and 6 fatty acids), and virus and insect tolerance, but most of these have not had a major impact yet. In general, despite the exceptional advance of genomic knowledge, our ability to define genes that increase yield per plant or per hectare has been most disappointing.

One concludes that the global agricultural situation has major challenges: less optimal land, more weather uncertainties, increased fuel and energy costs, and a society sensitivity towards gene transfer. This situation is made more complex by the need for renewable fuels, caused by the economic concept of 'Peak Oil', and the associated drive towards biological fuel sources.

Biofuel

Biofuel is a storable energy form based on biological processes. This compares to 'renewable energy', which is based on the harvesting of natural processes like wind or solar energy, but its products, namely electricity, are difficult to store. An airplane, for example, is not well served by electricity obtained from a solar panel; instead, aviation biofuel (kerosene Jet A1 fuel) is needed.

The biofuel industry itself is ancient. Thousands of years ago our ancestors harvested solar energy and plant growth through repeated wood harvests for local firings in stoves and ovens. Indeed, the system was sustainable as CO_2 produced from combustion entered the atmosphere but was re-assimilated by photosynthesis in the following time period. Demand was low as the population was small.

Overpopulation and industrialisation terminated that process. Today, we need large fuel supplies to facilitate transport (surface, water and air), industrial activity like mining, and electrification of off-grid regions.

Different organisms are being tested and explored as potential feedstocks for biofuel industry. Most likely it will not be just one species that will satisfy the industrial and economic needs of different continents and their ecosystems. Biofuels can also be synthesised from urban, agricultural and industrial waste. Solid materials like wood chips or corn stalks are being converted to liquid fuels and/or biofuel gases. A major challenge in this area is the efficiency and infrastructure cost. For example, cellulose can be converted to biogas or ethanol, but at best with only a 17% yield, implying a huge fermentation cost and a large residue. It may work on the local pig farm where manure is converted to biogas, but what about major urban centres?

At present, the choices are limited to algae (both fresh water or marine), corn, sorghum, oil palm, biomass for eucalypts, or similar fast-growing plants (including several C4 photosynthesis grasses like *Miscanthus giganteus* or switchgrass). A major point regarding all these choices is the issue of sustainability. In other words, can the production be maintained with a total energy gain?

Key to this argument is the competition with food crops. This immediately removes a food crop plant (such as soybean or peanut) as a potential biofuel source plant. Second, the biofuel plant must not compete with limited resources needed for food production. Land itself is a major aspect; as previously shown, the global environment is actually facing decreased land availability. Thus the biofuel plant needs to grow efficiently on marginal — meaning low agricultural productivity (LAP) — land. Third, the biofuel plant must not compete with food crops for water and fertilisers. Using marginal land lowers the average fresh water availability and thus removes these areas from direct competition with crops. However, fertilisers, supplying essential nitrogen, phosphorus and sulphur, are probably more important in such marginal land regions.

Elemental needs for plants growth can be viewed as a pyramid. Clearly, plant productivity needs carbon assimilation through photosynthesis; however, solar energy for that is literally unlimited. The second most important element is nitrogen (N), then tenfold less phosphorus (P), then again tenfold less sulphur (S). Elements such as magnesium (Mg), potassium (K), calcium (Ca) and trace elements like zinc, cobalt and molybdenum are also needed, but often are available because of low requirements. Nitrogen in a reduced form used to be supplied to plants through organic manure, then industrial fertiliser. The rise of crude oil price has led to a substantial increase in the cost of nitrogen fertilisation. Currently, ammonium nitrate markets at around US$540 per 908 kg NH_4NO_3 (a short ton). Amazingly, modern agricultural practices supply large amounts of nitrogen fertiliser per hectare. For example, corn, rice, oil palm and canola are commonly supplied with 150–200 kg of nitrogen fertiliser per hectare per year. Banana crops in Australia receive 600 kg/ha/annum! Clearly, these are high rates both in terms of costs and the environmental impact of the crop both pre- and post-application.

The overall conclusion to the arguments touched upon here is that we need less fossil fuel consumption, more use of under-utilised land, increased agricultural productivity, and an effective bulk supply of biofuel feedstock from a plant species that does not increase the energy and environmental problems already associated with bulk food production.

Pongamia pinnata as a biofuel feedstock

Pongamia pinnata (also called *Millettia*) is an outcrossing (therefore heterogenous seed) subtropical/tropical legume tree characterised by fast growth, tolerant growth habits, and a large annual seed production with high (35–35%) vegetable oil content.[1,2,3] This diploid tree (which means it has two sets of chromosomes) is native to the region between northern Australia and India, but is also found in Hawaii, Florida, and Dubai. The non-edible seed oil (50–55% mono-unsaturated oleic acid) is easily extracted by pressure or solvent, then converted to biofuel by transesterification (to biodiesel) or hydrogenation (to aviation A1 jet fuel). The tree has long been used in India for lantern and cooking stove fuel; it has only gained recent visibility as a feedstock for industrial biofuel production.[4]

Pongamia is a legume species and as such has the genetic ability to form a nitrogen-fixing symbiosis with soil bacteria, called ‘rhizobia’. The resulting root nodules house the bacteria for valuable nitrogen fixation; that is, nitrogen gas from the air (literally unlimited) is converted by the bacterium to plant-usable ammonia, replacing the need for externally supplied nitrogen fertiliser. The overall process is subject to in-depth scientific analysis worldwide, though research on biofuels has primarily focused on annual species such as soybean, pea, bean and medic.[5]

Research in the author’s laboratory contributes to the genetic, biochemical and physiological knowledge of the tree.[6,7,8,9] Elite specimens of the tree, found planted in horticultural situations based on the tree’s shade and floral benefits, have been selected and are being tested as clonal cuttings in different Queensland locations, to match genotype to environment. Oil composition and content as well as seed cake properties are being investigated, as is the nodulation and nitrogen fixation process.[10,11] Jensen et al. have presented a detailed analysis and overview of the benefits of a legume for mitigation of the GHG issue,[12] while Klein-Marcuschamer et al. have modelled the energetics of fuel conversion.[13]

Many questions remain unanswered about the overall utility of pongamia as a biofuel feedstock. Little is known of the pests of pongamia. Large-scale plantations, especially with clonal material, will surely amplify the disease pressure. Harvesting the millions of seed needs mechanisation; appropriate technical solutions seem to be olive tree or citrus tree harvesters, but the pongamia biofuel industry is just entering the scale where this is required.

Worldwide there is speculation and investment. Even the United States has spawned a company, called TerViva, which is looking at the potential of the crop; similar efforts exist in Australia, Cambodia, Brazil, Paraguay, Spain, India, and Indonesia. Strong research now emerging from Indian laboratories is adding to the past, more descriptive literature from that country. The University of Queensland laboratory is willing to interact with any of these interested parties, subject to appropriate funding arrangements for science and development.

Yes, we can afford biofuel and bioenergy, but we have to be informed of the scientific complexities of the crop and the related industry. The correct biological basis (such as nitrogen fixation and large seed yield) needs to be accepted to develop an industry in the next two decades that will supply a proportion of the biofuels and bioenergy required for transport and local electrification.

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