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Symposium on “Scientific Issues on Biofuels”, Sao Paulo
*Session 3:* Sustainability of Biofuels
May 25, 2010

# Sustainability of biofuels and scope of carbon sequestration: case studies of *Jatropha* and *Kappaphycus* seaweed


Pushpito K. Ghosh

Central Salt & Marine Chemicals Research Institute (CSIR)

G. B. Marg, Bhavnagar 364002, Gujarat, India

www.csmcri.org



**Acknowledgement**

- Colleagues in CSMCRI who have worked with passion and contributed in this area.
- Daimler Corporation; DEG; University of Hohenheim; General Motors; US Department of Energy; Pepsico India; Aquagri; Government agencies
- Brazilian Academy of Sciences, São Paulo Research Foundation and the Inter Academy Panel for the kind invitation

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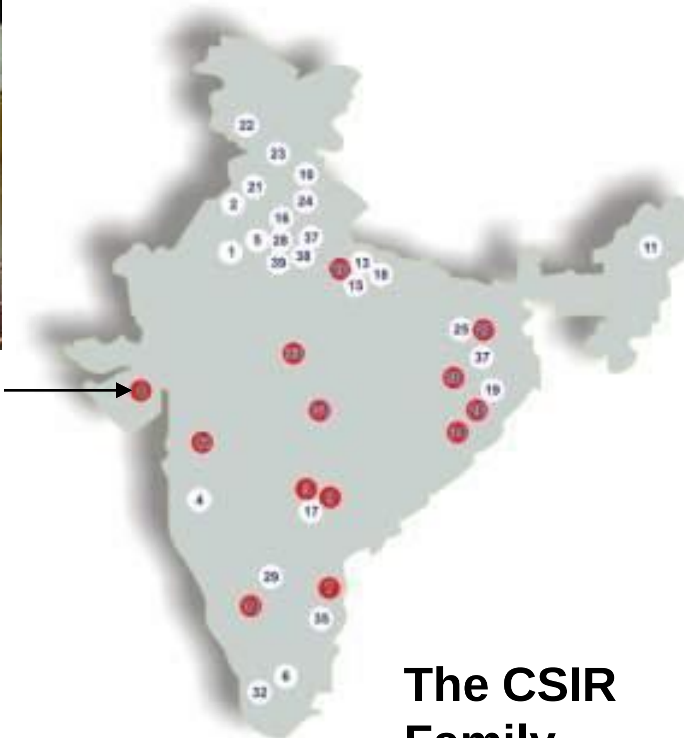
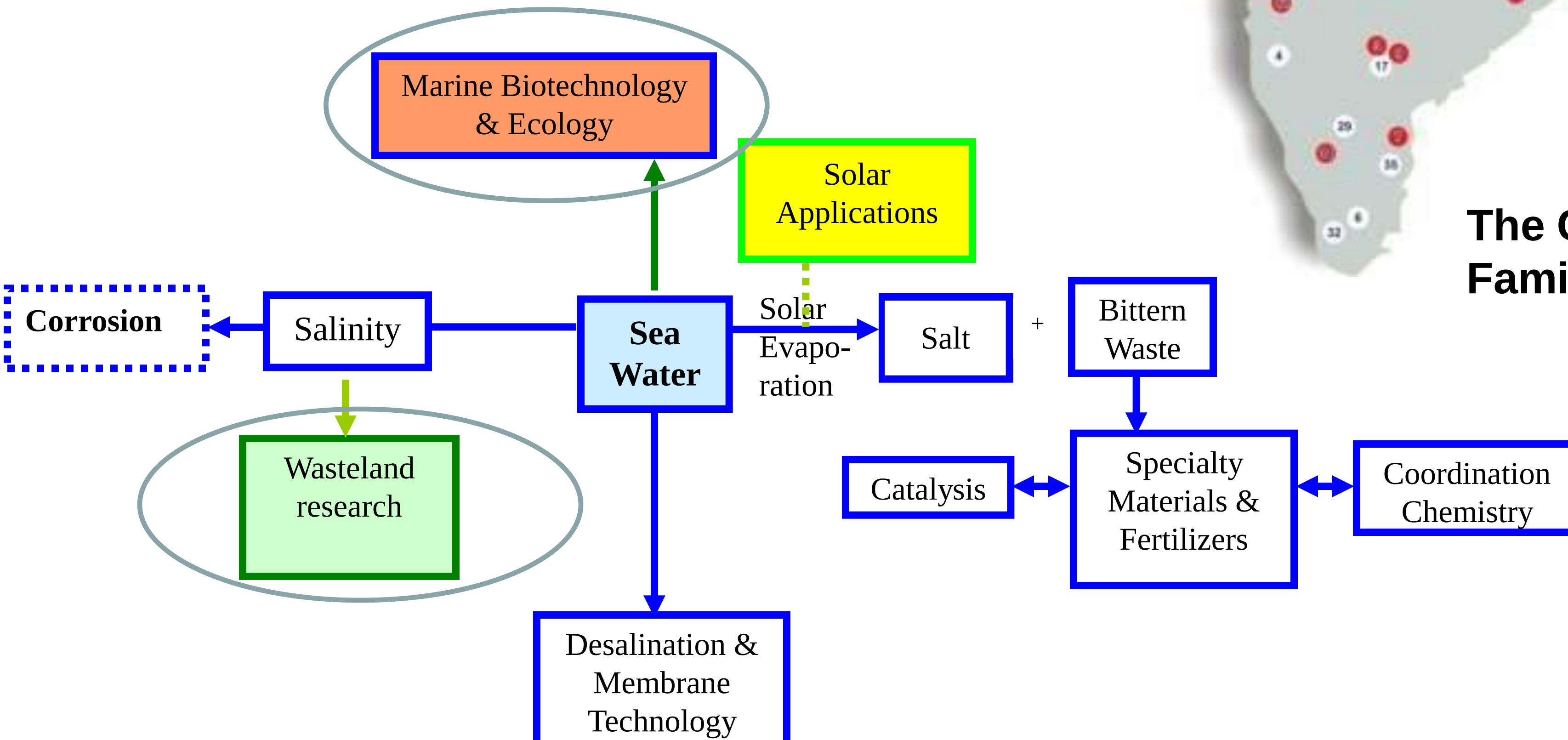


## The CSIR Family



# It was the desire to transform wastelands for biofuel, and to avoid the dilemma of *"food vs. fuel"*, that led to our involvement in Jatropha

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


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

From: NATURE, *449*, pp. 652-655, 2007

**The vehicle has now completed over 130,000 km without any modification (May 2010).**

*U.S. patent No. 7,666,234, 23 Feb, 2010 (to CSIR)*

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# The Mercedes trial run across India in April 2004 using B100 *Jatropha* biodiesel with the goal of sustainable mobility sparked global interest in *Jatropha*.

**Test run at 18,400 feet (Aug 2005)**

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Emission Data courtesy DaimlerChrysler

| | | | Actual Measurements | | | |
|---|---|---|---|---|---|---|
| | Units | EU3 Limits | Fossil Diesel | Bio-Diesel | Changes against limits, % Fossil | BioDiesel |
| CO | g/km | 0,64 | 0,08 | 0,11 | -88 | -83 |
| HC | g/km | 0,56 | 0,04 | 0,02 | -92,9 | -96,4 |
| NOx | g/km | 0,5 | 0,37 | 0,39 | -26 | -22 |
| Particulates | g/km | 0,05 | 0,03 | 0,01 | -40 | -80 |
| Fuel Consumption | L/100 km | | 6,47 | 6,58 * | | 1,70% |

*** The heating value of BioDiesel is 8-9% lower than of fossil Diesel liter for liter!!**

*Further tests at the **Austrian Biofuels Institute** (ABI), which pitted the CSMCRI's jatropha biodiesel against fuels from other feedstocks, showed that it "clearly outperformed biodiesel from rapeseed, sunflower and soya bean oil in [its lack of a propensity to oxidize]," says the ABI's Werner Körbitz, adding that the fuel "showed a fully satisfying performance concerning power, efficiency and emissions".*

***"The Little Shrub that Could – May be"*, D. Fairless, *Nature*, 449, 2007, pp. 652-655.**

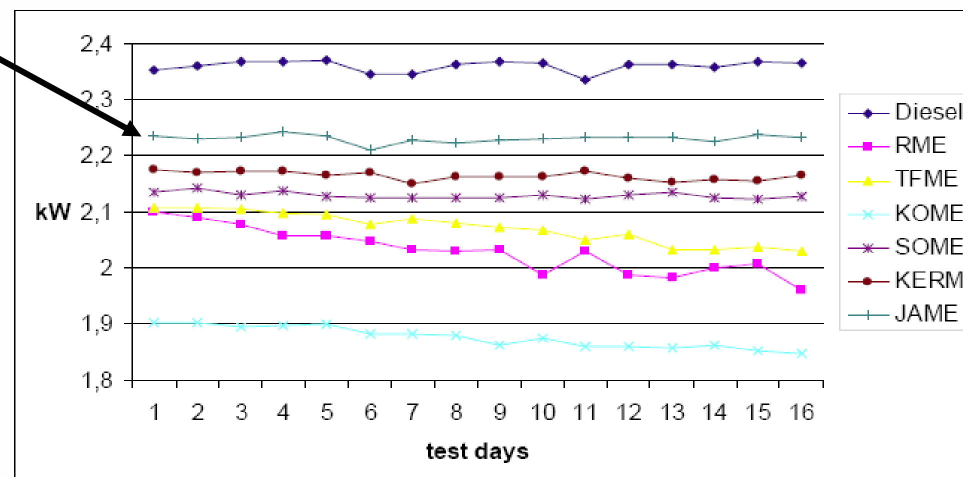


*Figure 10: Trend of engine power of the long term run with test fuels*

## Mooting the concept of “local use of local produce”

Husk from deshelling machine

Briquetting operation

Briquettes (3900 kcal/kg) being used to fire the boiler. The steam is used for oil expelling and other applications. The ash is ploughed back into the field. The briquettes also burn nicely in a chuhla with low smoke.

Seed from deshelling machine


Generator fueled by B100 JME being used to drive the oil expeller (at left)

Elite accession

**2 tons of briquettes and 3 tons of oil cake are obtained per ton of biodiesel!**

# Energy and $CO_2$ balance based on CSMCRI's primary data of mature *Jatropha* plantation on semi-arid wasteland and downstream operation to briquette and B100 biodiesel

| **Operations at Mature Stage**[c] | **Energy Requirements of production (MJ/t of dry Jatropha fruit)** | **$CO_2$ released/ sequestered (kg)** |
|---|---|---|
| **Inputs** | | |
| Manpower<br>(Human labour (average): 1.61 MJ/manday @ 52 mandays/ton of fruit | 84 | |
| Irrigation<br>( cm/tonne of fruit assuming 3 tons of fruit per hectare is realised) | 127 | |
| Fertilizers usage other than oil cake and seaweed<br>(Fertilizer average : N-60.1 MJ/kg; P-10.35 MJ/kg; K-11.10 MJ/kg and applied at the rate of 20: 2.9: N:P:K requirement/ton of fruits assuming 3 tons fruit/hectare)<br>(it is also assumed that ash from burning of briquette will be ploughed back into the plantation to conserve inorganic minerals and micronutrients) | 1341 | |
| Pesticides<br>120 MJ/kg (contingency) | 40 | |
| Manure/Dry fruit transportation | 78 | |
| Briquette and biodiesel production | | |
| Manpower | 14 | |
| Power consumption | 300 | |
| Total energy consumed/$CO_2$ release | 1984 | 396 |
| Output | | |
| Briquette (0.33 tons) | 5420 | |
| Biodiesel (0.142 tons) | 5638 | 456 |
| Total energy gain/ $CO_2$ sequestered | 11058 | 940 |
| Net balance (Output/input) | 5.57 | 2.02 |

Oil cake is ploughed back in the field. Calorific value and $CO_2$ sequestered in other co-products in crude form are not considered in the computation.

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# Performance of plants raised from cuttings of IC-565735 identified as the best performing provenance at Mohuda, Berhampur, Orissa

| | Mean seed yield in kg/plant (N=10) | | | | |
|---|---|---|---|---|---|
| Year | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 |
| Seed yield | 0.30 | 0.70±0.2 | 1.40±0.8 | 2.00±0.8 | 2.04±0.6 |

**Date of planting-** Jan 2003;
**Planting material-** cuttings of IC-565735
**Spacing-** 4X3m (833 plants/ha); Irrigation- once a month with 30 L/plant during non-rainy months
**Fertilizer dose-** During 2005 and 2006- N- 45 kg/ha (by urea); $P_2O_5$- 30 kg/ha (by Single Super Phosphate); $K_2O$- 20 kg/ha (by MOP) ; FYM- 2.7 kg/plant; Jatropha cake- 1.2 kg/plant.
During 2007 -DAP @ 200g/plant and oil cake 1kg/plant
During 2008 and 2009– 40g/plant of NPK fertilizer of grade 46:48:24, DAP@ 100g/plant and oil cake 1 kg/plant
**Time of fertilizer application-** ½ N and full P and K at just before onset of monsoon and ½ N just before flower initiation

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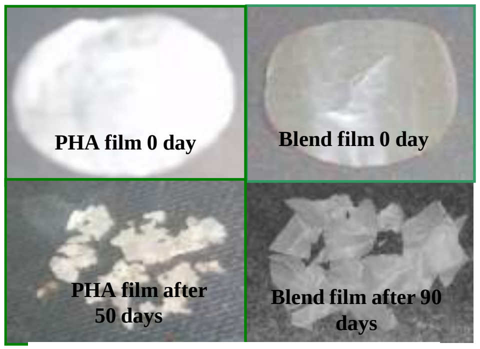
Jatropha plant with fruit

Jatropha seeds

Crude Glycerine

Jatropha deoiled Cake

Jatropha biodiesel wastes




Biodegradability of PHA in the moist garden soil

Jatropha biodiesel production plant

Bacterial Inoculum

Marine bacteria MTCC-5345 isolated from Indian waters

PHA powder

PHA film

## India Develops Plastics from the Jatropha Plant

April 9, 2010

A new, potentially important, source of bioplastic has been discovered in India- the Jatropha plant, which is already being processed to produce diesel fuel. The Salt and Marine Chemical Research Institute (CSMCRI) of Bhavnagar, India is using a local microbe to produce plastic from the glycerol byproduct of biodiesel production.....

**Doug Smock**
Materials Editor, Design News
www.designnews.com
Needham, MA

Microbial heterotrophic production of bioplastic utilizing Jatropha biodiesel residues as sole nutrients

1838/DEL/2009 dated 7 Sept 2009

*"The CSMCRI project has benefited from a realistic approach from the start"* – Katharine Sanderson, Nature Correspondent, Climate Feedback blog, nature.com

nature.com

# Climate Feedback

the climate change blog

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## Wonder weed plans fail to flourish

Bookmark in Connotea

This week in Nature you can read the first (subscription) of four articles unpicking the business of biofuels. First up is jatropha - the shrub that promised to give drought-ridden countries boundless oil supplies. The reality has turned out to be somewhat different. After a period of hype and over enthusiasm, investments have dried up, somewhat like the promise of oil from arid land.

Jatropha definitely still has a future, but the plant genetics really need to be better developed and a number of companies are now doing this, including London-based D1oils - a company which hit trouble earlier this year when a deal with oil giant BP fell through.

We also catch up with Pushpito Ghosh, director of India's Central Salt and Marine Chemicals Research Institute. Nature first encountered Ghosh in 2007 when jatropha was still promising the Earth. His project seems to have benefited from a realistic approach from the start. Here we see a photo taken just last week at a CSMCRI plantation in Mahuda, Orissa. Each plant in this kind of harvest gives 1.75-2.25 kg of seeds, which have the oil extracted and the waste turned into briquettes.

The series continues next week with a look at bioalgae as a potential fuel source. After that comes cellulosic bioethanol, followed by the potential for a 'green gasoline' to be used as a simple drop-in-fuel replacement.

*Katharine Sanderson*

Image: CSMCRI

Posted by Anna Barnett on September 17, 2009

Categories: Energy, In the News, Katharine Sanderson | Permalink | Comments (1) | TrackBacks (0)

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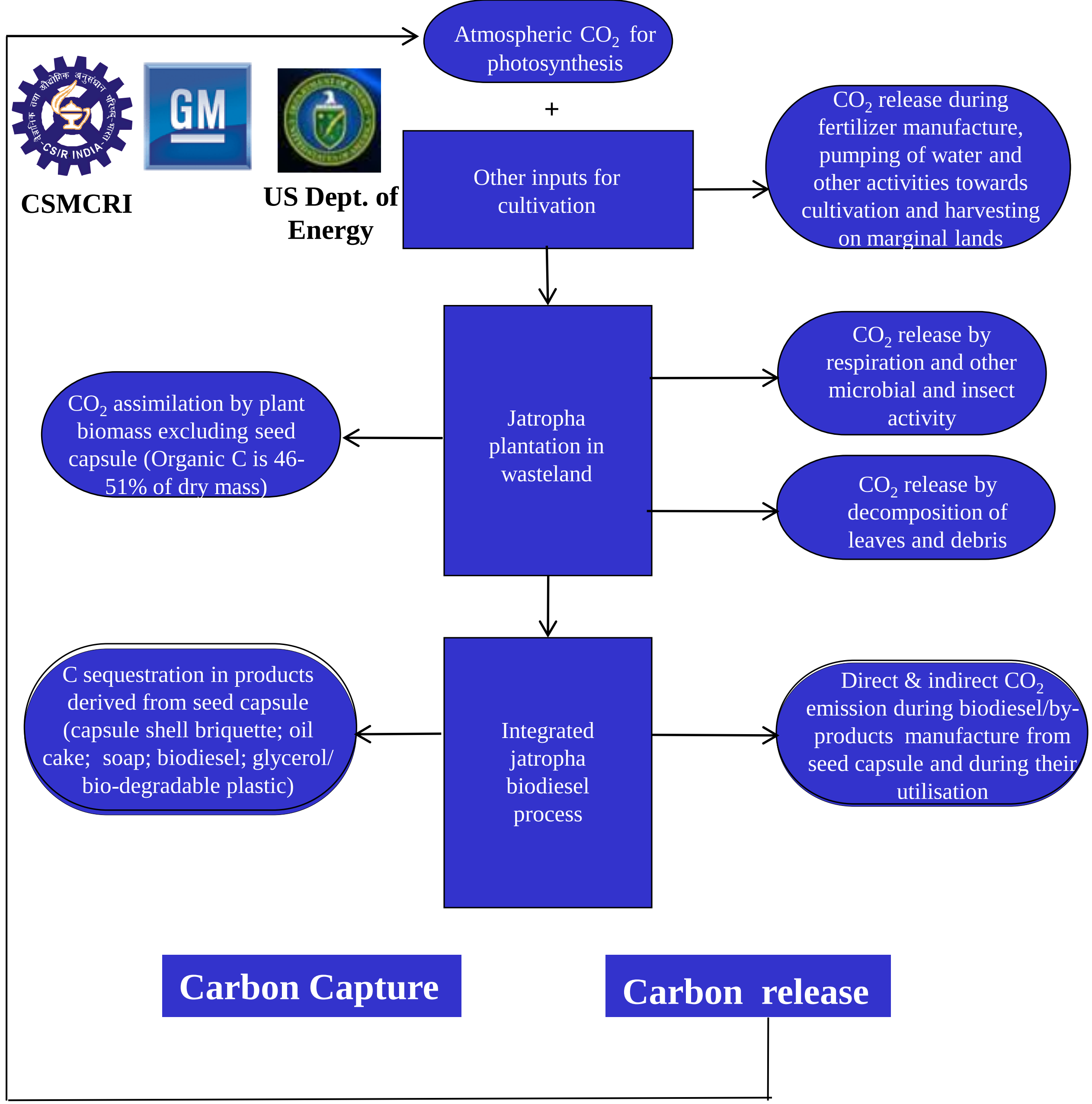


**Enhancing seed productivity and reducing the carbon footprint for Jatropha biodiesel from marginal land is the focus of the collaborative project supported by *GM and US Dept. of Energy***

# Ushering in Commercial Cultivation of Seaweed in India: A relevant technology for all countries with a long coast line

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*Kappaphycus alvarezii:* From a single twig in 1996 to thousands of tons after a decade!

ECOLOGY

## Seaweed Invader Elicits Angst in India

NEW DELHI—An effort in southern India to raise coastal farmers out of poverty by paying them to cultivate red algae for a food additive has gone awry. Last month, botanists reported that the alga, *Kappaphycus alvarezii*, has invaded coral reefs in a marine reserve in the Bay of Bengal. Experts are trying to establish who let the seaweed escape into the wild: a government lab, a multinational company, or careless farmers.

The saga began in 1996, when the Central Salt and Marine Chemicals Research Institute (CSMCRI) in Bhavnagar launched a project to grow the algae in perforated bags in the open sea and extract carrageenan, a gelatinous compound used to stabilize or add texture to products as diverse as toothpastes and mocha lattes. In 2000, CSMCRI transferred the technology to PepsiCo India Holdings Private Limited in Gurgaon, whose executive vice president, Amit K. Bose, told *Science* that since 2001 the company has been "supporting and subsidizing" local farmers to cultivate the alga offshore. The seaweed is grown on tethered rafts in shallow water; algae is harvested and dried and exported to countries such as Malaysia and the Philippines, which extract the carrageenan.

The commercial cultivation is near the edge of the Gulf of Mannar Marine National Park, a 560-square-kilometer reserve that's home to more than 100 species of corals and mammals such as sea cows and dolphins. Off Kurusadai Island in the reserve, "no part of the coral reefs was visible in most invaded sites, where [the algae] doomed the entire colonies and occupied almost all ridges and valleys of the coral landscape," a team led by botanist S. Chandrasekaran of Thiagarajar College in Madurai reported in the 10 May issue of *Current Science*. It's not clear if the alga has spread to other parts of the reserve.

This isn't the first time the alga, native to the Philippines, has invaded new turf: In 1999, it colonized coral reefs in Hawaii, according to the University of Hawaii, Manoa. For that reason, some prominent researchers, including M. S. Swaminathan, an agricultural scientist at M. S. Swaminathan Research Foundation in Chennai who now serves in Parliament, had opposed bringing the alga to India in the first place.

No one has taken responsibility for *K. alvarezii*'s escape. Whoever is deemed responsible could be prosecuted for damaging habitat under the Indian Wild Life Protection Act of 1972, says P. K. Manohar, a lawyer with Legal Action for Wildlife and Environment in New Delhi.

***Moving in.*** *Kappaphycus alvarezii* growing on coral in the Gulf of Mannar Marine National Park.

Bose acknowledges that PepsiCo promoted contract farming of the algae to serve the community by helping impoverished farmers. The company guarantees that it will buy all the farmers' annual production of *K. alvarezii*, amounting to 100 to 200 metric tons of dry seaweed; all the dry seaweed is exported, Bose says. He denies that PepsiCo played a role in the alga's escape into the marine reserve. Instead, he suggests that CSMCRI's cultivation trials are "the root cause for its bioinvasion at [Kurusadai]."

CSMCRI's director, Pushpito K. Ghosh, says he is "quite puzzled as to what may have happened." He and his colleagues argue that strong currents could have swept algal twigs from commercial farms near Kurusadai or from his institute's trial cultivation site. "Another possibility, which must not be ruled out, is clandestine experimentation by unscrupulous elements," Ghosh says, without elaborating. Chandrasekaran calls that an "outlandish explanation" and notes that no one is allowed to visit Kurusadai Island without written permission from reserve authorities. No matter how the seaweed colonized Kurusadai, Ghosh says, "there is no question of CSMCRI disowning responsibility."

PepsiCo has said it will pay for a wider survey of *K. alvarezii* in the marine reserve as well as measures to scoop it up. But it may be too late to get rid of the algae, says Swaminathan. "All that we can now do is restrict the extent of bioinvasion."

—PALLAVA BAGLA





No pressure on agriculture land

No requirement of fresh water for irrigation

No requirement of fertilizers or pesticides

Environmental issues and risks need careful understanding of course

# Integrated method for recovery of phycocolloid and sap from seaweed

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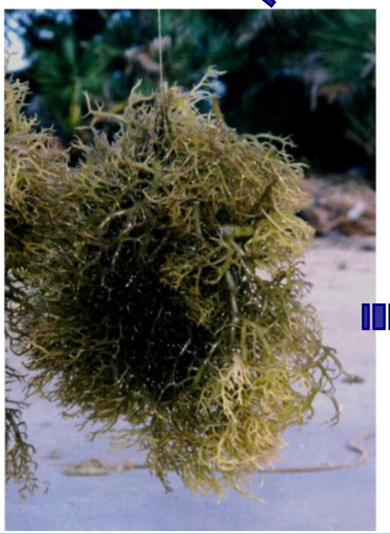
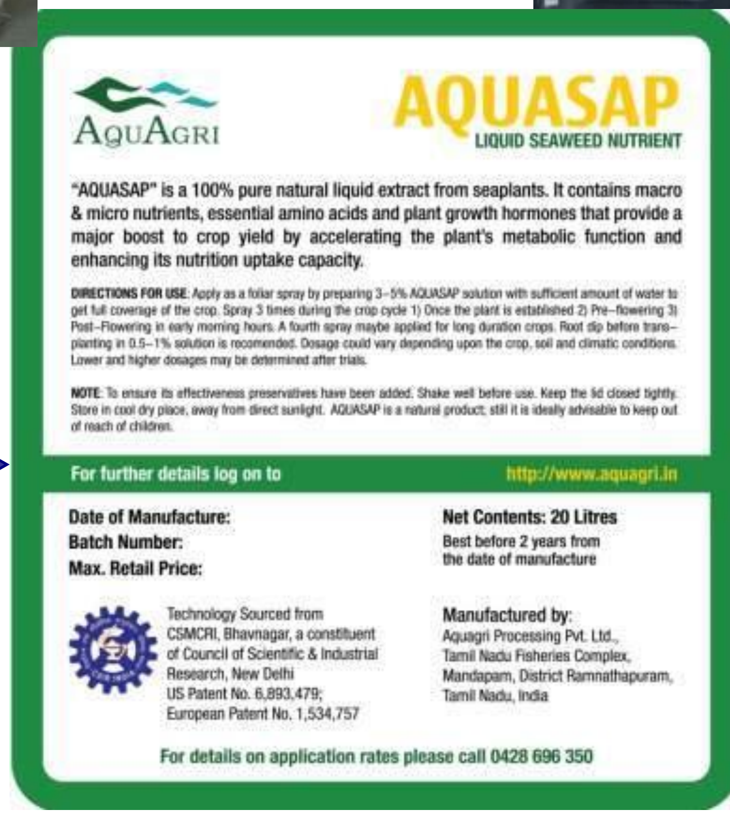
Granules are a source of calories/ethanol and the ash is a potash-rich fertilizer



**Kappaphycus alvarezii**



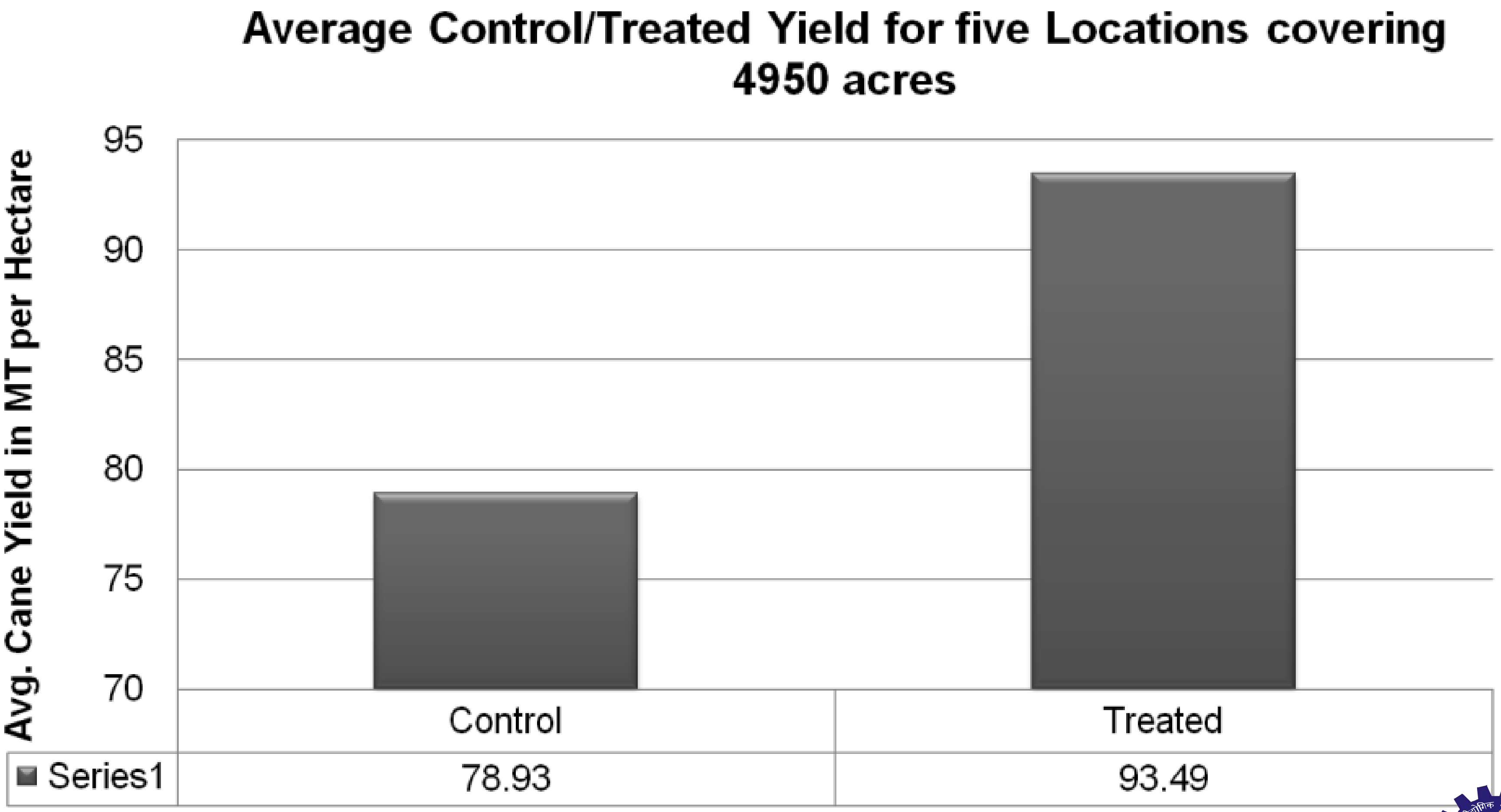

**Seaweed Sap**

70 TPD plant capacity

*US Patent No. 6,893,479; EP 1534757 (to CSIR)*

*J. Agric. Food Chem.* 2010, *58*, 4594–4601

# Graphical summary of sap trial on sugarcane yield in TEIL command area (2009)




Data courtesy M/s Aquagri Limited (licensee); Similar trends have been indicated previously by M/s Renuka Sugar Mills for a 1000 acre trial

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# First trial of new generation E10 gasohol

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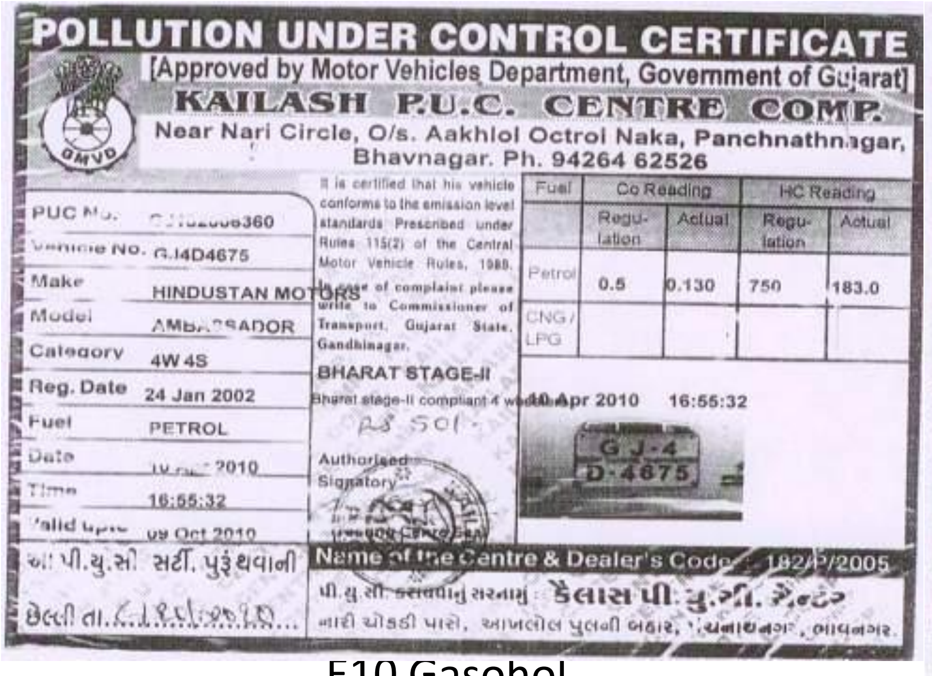
CSM E10 Gasohol formulated with ethanol from seaweed

**POLLUTION UNDER CONTROL CERTIFICATE**

[Approved by Motor Vehicles Department, Government of Gujarat]

**KAILASH P.U.C. CENTRE COMP.**

Near Nari Circle, O/s. Aakhlol Octroi Naka, Panchnathnagar, Bhavnagar. Ph. 94264 62526

| | |
|---|---|
| PUC No. | [illegible]360 |
| Vehicle No. | GJ4D4675 |
| Make | HINDUSTAN MOTORS |
| Model | AMBASSADOR |
| Category | 4W 4S |
| Reg. Date | 24 Jan 2002 |
| Fuel | PETROL |
| Date | 10 [illegible] 2010 |
| Time | 16:55:32 |
| Valid upto | 09 Oct 2010 |

It is certified that his vehicle conforms to the emission level standards Prescribed under Rules 115(2) of the Central Motor Vehicle Rules, 1989. In case of complaint please write to Commissioner of Transport, Gujarat State, Gandhinagar.

BHARAT STAGE-II

Bharat stage-II compliant 4 wheeler

| Fuel | Co Reading | | HC Reading | |
|---|---|---|---|---|
| | Regulation | Actual | Regulation | Actual |
| Petrol | 0.5 | 0.130 | 750 | 183.0 |
| CNG / LPG | | | | |

10 Apr 2010 16:55:32

GJ-4 D-4675

Authorised Signatory

Testing Centre Seal

આ પી.યુ.સી. સર્ટી. પુરૂં થવાની છેલ્લી તા.

Name of the Centre & Dealer's Code : 182/P/2005

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નારી ચોકડી પાસે, આખલોલ પુલની બહાર, પંચનાથનગર, ભાવનગર.

E10 Gasohol

**POLLUTION UNDER CONTROL CERTIFICATE**

[Approved by Motor Vehicles Department, Government of Gujarat]

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| | |
|---|---|
| PUC No. | [illegible] |
| Vehicle No. | GJ4D4675 |
| Make | HINDUSTAN MOTORS |
| Model | AMBASSADOR |
| Category | 4W 4S |
| Reg. Date | 24 Jan 2002 |
| Fuel | PETROL |
| Date | 21 Apr 2010 |
| Time | 10:29:09 |
| Valid upto | 20 Oct 2010 |

It is certified that his vehicle conforms to the emission level standards Prescribed under Rules 115(2) of the Central Motor Vehicle Rules, 1989. In case of complaint please write to Commissioner of Transport, Gujarat State, Gandhinagar.

BHARAT STAGE-II

Bharat stage-II compliant 4 wheeler

| Fuel | Co Reading | | HC Reading | |
|---|---|---|---|---|
| | Regulation | Actual | Regulation | Actual |
| Petrol | 0.5 | 0.100 | 750 | 121.0 |
| CNG / LPG | | | | |

21 Apr 2010 10:29:09

GJ-4 D-4675

Authorised Signatory

Testing Centre Seal

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Regular petrol

Energy- and carbon balance for seaweed cultivation integrated with increase of sugarcane productivity through the application of seaweed sap: A true bonanza!

| **Operations** | **Energy Requirements (MJ/t fresh biomass)** | **$CO_2$ released/ sequestered (kg)[c]** |
|---|---|---|
| Farming operation | 7 | |
| Ropes | 1 | |
| Transportation | 9 | |
| Sap extraction<br><br>Sap application in sugar cane field | 40.2<br><br>10 | |
| Total Loss | 67.2 | 7.2 |
| Granules ( dry wt) | 1680 | 2156 |
| Additional yield of sugar cane (57.5 tons from 3.5 ha assuming very conservative 15% yield increase) | 300,000[a] | 33,000[c] |
| Total Gain | 301,680 | 35,156 |
| Net balance (Output/input) | 4,489 | 4,882 |

[a]Sugar cane contains 30% dry matter with gross energy value of 17.35 MJ/kg of dry matter (1http://www.vt.tuwien.ac.at/Biobib/fuel239.html); [c]40% Carbon content in dry matter of sugar cane is assumed.

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# Conclusions

- Given that India is short of arable land, we are focusing on biofuels from waste biomass, wasteland and the sea.
- The energy output to input ratio for *Jatropha* biodiesel and energy briquette is ***5.6*** for cultivation on marginal land with 3 tons dry fruit yield per annum. The stage is set for a cooperative, decentralized model of operation. Further, the target is to climb up to a value of 7-8.
- *Kappaphycus* cultivation in the sea for sap to raise sugarcane productivity has opened up a massive opportunity to sequester carbon in a most efficient and sustainable manner, with unprecedented energy output to input ratio. Additionally, the residue is demonstrated to be a source of ethanol which does not infringe on food – a key consideration for India.
- There is great scope for inter-academy collaboration given the complementary strengths.

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# Thank You