California Energy Commission
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Title of Proposed Initiative: Carbon-Neutral Biomass Grown in the Open Ocean

Investment Area: Applied Research and Development

Electricity System Value Chain: Generation

Issues and Barriers: California, the nation and the world desperately need carbon-neutral sources of primary energy to combat climate change. Typical renewable energy sources don't generate enough Watts per square meter of collection area (Table 1[1]) to meet the per capita need. To get the thousands of Watts needed per capita requires huge areas be devoted to renewable energy conversion.

California has about 750 miles of coastline, and has access to the 200 miles of exclusive economic zone which extends beyond the 12 mile territorial boundary. If 90% of the economic zone is available for ocean farming, that's more than 350 billion square meters of largely-unused renewable resource collection area. Marine plants, such as California Giant Kelp, are among the fastest-growing of all plants - able to convert sunlight at 1 W/m^2 or more. Kelp produces biomass year around with a photo-synthetic efficiency of 6-8% compared to land based plants at 1.8-2.2%.[2] Further, Giant Kelp can be harvested from the top section of the plant 3-4 times a year while leaving the base of the plant in place to continue growing on an artificial substrate.[3] Thus California has a marine resource capable of producing the U.S. average 9,500 Watts per person of carbon-neutral renewable energy. No comparable terrestrial area is available without an extreme land-use controversy.

Power per unit land or water area	
Wind	2 W/m^2
Offshore wind	3 W/m^2
Tidal pools	3 W/m^2
Tidal stream	6 W/m^2
Solar PV panels	5–20 W/m^2
Plants	0.5 W/m^2
Rain-water (highlands)	0.24 W/m^2
Hydroelectric facility	11 W/m^2
Solar chimney	0.1 W/m^2
Concentrating solar power (desert)	15 W/m^2

Table 25.1. Renewable facilities hav to be country-sized because all renewables are so diffuse.

Table 1: From *Sustainable Energy Without The Hot Air*, by David JC MacKay (Professor of Physics at Cambridge, UK, UIT 2008)

Conversion of energy captured in marine biomass is relatively straightforward. Dairy farmers have, for many years, been economically converting manure into methane by anaerobic biodigestion.[4] Marine biomass has approximately the same properties for biodigestion into methane as manure, and is especially easy-to-process because it has little lignin and no cellulose.[5,6] Following the oil embargoes of the 1970s, as a national-security issue, the U.S. Navy extensively studied the cultivation of giant kelp in the open ocean[7] and, when this analysis is updated to current prices, it is found that wet kelp could be delivered to the dock in California for as little as $2/GJ. This suggests that economical biodigestion methods as perfected by the diary industry can deliver methane into the electric grid generators of California at a price competitive with natural gas (now selling for over $5/GJ, even with the depressed prices caused by the fracking boom).

Barriers to this technology include the obvious issues related to the apparent complexity of off-shore operations. However, U.S. industry is remarkably resourceful and innovative, and it is worth a modest investment to see what sorts of proposals might be received in response to a solicitation for economically-viable approaches to this problem.

It is important to mention another barrier. To qualify for funding, the State of California has been forcing renewable energy start-ups to partner with deep-pocket investors to meet cost sharing requirements. Many current deep-pocket firms with an interest in the field are holding huge amounts of yet-to-be-tapped underground carbon fuels on their balance sheets. So their economic incentive is to convince governments that there is no viable alternative to extracting and burning that carbon. They have every incentive to acquire and bury promising patents and technologies as documented in an article about Chevron and Catchlight Energy.[8]

Initiative Description and Purpose: This initiative would seek proposals from industry and academia to explore the feasibility of cultivating high-yield marine plants in the ocean off California. To be practical, the proposed cultivation approach must not interfere with protected coastal zones, shipping, commercial fishing or recreation. It must take full advantage of the fact that ocean farming need not rely on supplies of fresh water or artificial fertilizers, nor does it take any human food out of the supply chain. Attractive proposals, in terms of projected energy price, greenhouse gas footprint, and anticipated pace of development, would be funded for an exploratory phase of development.

Stakeholders: Groups that should support this initiative are all that seek to reduce the impact of climate change - that is, everyone except those who hold a large amount of fossil carbon fuels on their balance sheets. On behalf of the ratepayers, this offers an affordable solution to global climate change.

Background and State of the Art: In 2008 the Battelle Pacific Northwest National Laboratories released a study "Techno-Economic Feasibility Analysis of Offshore Seaweed Farming for Bioenergy and Biobased Products" which states in the abstract "advances in open ocean engineering and the current energy economics, provide the basis and incentive to develop a novel approach to open ocean farming...in conclusion, macroalgae, i.e. seaweeds, represent an unrealized biomass potential to meet future societal needs for renewable energy".[9]

ARPA-e has recently funded research to convert kelp to liquid fuels.[10] EcoShift Consulting recently conducted GHG intensity analysis of a seaweed-based ethanol product that performs significantly better than ethanol made from other feedstocks.[11]

The U.S. Navy in San Diego funded an extensive study of open-ocean farming of kelp as a source of energy in the 1970s. The analysis and results are available in multiple volumes.[12] Marine BioEnergy, Inc. of La Cañada, CA[13] has recently updated this analysis to current prices and methods and concluded that a modern and improved implementation of this approach can deliver carbon-neutral kelp to the dock in California for an estimated $2.09/GJ.

Justification: The potential market for carbon-neutral renewable energy is huge - ideally replacing all of the fossil fuels used in the world. The U.S. per capita rate of energy use is about 9.5kW (averaged 24/7/365; see the World Bank figures[14]). With kelp storing energy at the rate of 1 W/m^2 (again averaged 24/7/365), all the world's energy needs can be met by ocean farming over a fraction of the world's oceans. California is well-positioned to be in the vanguard of this technology, and ultimately to export the technologies that enable this revolution in energy supply. The maximum market potential is literally many trillions of dollars per year - about a third of all energy currently goes to generate electricity that sells for greater than $30/GJ, another third is consumed as liquid transportation fuels selling for about $30/GJ, and the last third is used for heating buildings and industrial process heat at ~$5/GJ.[15] For electricity alone, the ~40M people in California spend about 45 billion dollars[16], and even more for liquid transportation fuels, both of which can be sourced from ocean farms. If California becomes the hub of this new worldwide industry, the jobs created to build the equipment that will enable this industry could easily number in the tens of thousands. This research is appropriate for public funding because it is in its infancy and yet, of all the possible solutions to climate change, it is by far the most attractive due to the fact that it does not require land, fresh water, artificial fertilizers, disruption of other industries or populations, nor does it create a risk of nuclear diversion or terrorism. Kelp farming and processing also provides for regular storage of fuels, from raw biomass to finished products in the pipelines and in storage tanks, similar to the storage of fossil fuels now.

Ratepayer Benefits: *GHG emissions mitigation/adaptation in the electricity sector at the lowest possible cost*; *Promote greater reliability* (due to the intrinsic energy stored in the biomass supply chain, as distinct from the highly-variable output of wind and direct-solar generators); *Potential energy and cost savings* (cost savings due to the significant, reliable supply of year-around, fast-growing biomass, and non-imported nature of the resource); *Environmental benefits* (eliminates land-use conflicts such as

damage to sensitive desert habitats); *Economic development* (local jobs in the ocean farming industry and the likelihood that, if successful, these systems can be exported to coastal regions all over the world).

Public Utilities Code Sections 740.1 and 8360: The proposed initiative is consistent with all elements of section 740.1., with special emphasis on (e)(4), which states that "The commission shall consider the following guidelines in evaluating the research, development, and demonstration programs proposed by electrical and gas corporations: (e) Each project should also support one or more of the following objectives: (4) Development of new resources and processes, particularly renewable resources and processes which further supply technologies."

Section 8360 relates to smart grid technologies. One of the biggest challenges for the smart grid is to avoid fluctuations caused by wind and solar. Kelp provides abundant energy storage through the intrinsic storage in the kelp-to-drop-in-fuel supply chain which implicitly cushions the grid from fluctuations caused by secondary sources such as wind farms and direct solar. With stored kelp-based fuel, utilities can have abundant carbon-neutral fuel for backup generators when fluctuations occur.

References (all websites accessed 7 Feb 2014):

[1] http://www.withouthotair.com/

[2] Ross, A.B, J.M. Jones, M.L. Kubacki, and T. Bridgeman, "Classification of macroalgae as fuel and its thermochemical behavior", Bioresource Technology 99, 2008, page 6494.

[3] Bird, K.T. and Benson, P.H. Eds, *Seaweed Cultivation for Renewable Resources* Developments in Aquaculture and Fisheries Science, Vol 16, Elsevier Amsterdam NL, 1987, p83.

[4] http://www.agmrc.org/media/cms/manuredigesters_FC5C31F0F7B78.pdf, Table 4 p5

[5] http://abe.ufl.edu/chyn/download/Publications_DC/Reports/marinefinal_FT.pdf

[6] Ross, 2008, see pages 6497 and 6500-6501.

[7] http://www.ntis.gov/search/product.aspx?ABBR=ERDAUSN1027761V1

[8] http://www.bloomberg.com/news/print/2013-04-18/chevron-defies-california-on-carbon-emissions.html
http://www.biofuelsdigest.com/bdigest/2013/04/19/who-killed-2-18-gasoline/

[9] http://www.scribd.com/doc/16595766/Seaweed-Feasibility-Final-Report

[10] http://arpa-e.energy.gov/?q=arpa-e-projects/macroalgae-butanol

[11] http://www.biofuelsdigest.com/bdigest/2013/11/20/bio-architecture-lab-ecoshift-make-waves-with-seaweed-based-biofuels/

[12] http://www.ntis.gov/search/product.aspx?ABBR=ERDAUSN1027761V1
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[13] http://www.patentstorm.us/patents/7905055/claims.html

[14] http://en.wikipedia.org/wiki/List_of_countries_by_energy_consumption_per_capital

[15] http://www.withouthotair.com/, page 116

[16] http://www.energy.ca.gov/2007publications/CEC-200-2007-015/CEC-200-2007-015-SF2.PDF Table ES-1 and http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a (CA, Nov 2013)