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Preliminary Design & Analysis of Low-Cost Concentrating Offshore Solar Energy Innovations

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Abstract

Innovations in offshore floating solar energy systems are presented, which cost-effectively leverage simple, low risk & elegant configurations for synergistically harvesting electricity & usable heat. Preliminary designs along with technical & cost analyses are presented for several systems suitable for private owners, public or commercial waterfront entities, utility-scale applications & enabling applications for cities with 100% renewable goals. Examples of cost-reduction enablers that reduce levelized cost of energy (LCOE) include use of lightweight low-cost inflatable subsystems for low-concentration reflectors, low-cost dual-axis tracking for a floating array, elimination of land use, and CPV liquid cooling that can also transfer usable heat for hot water, building, swimming pool or process heat as well as solar district heating/cooling and desalination. Synergistic integration of multiple offshore renewables including offshore solar, wind, tidal or ocean current, and ocean thermal energy systems (OTEC) is also presented as an enabling means to achieve minimized LCOE in some geographic locations.

Keywords: *solar, offshore, land use, low-cost, LCOE, innovation, concentrating, cogeneration, heating, CPV, heliostatic, tracking, electricity, heat, district heating, district cooling, efficiently, solar thermal, synergistic, wind, tidal, ocean, OTEC, desalination, 100% renewable*

1. Introduction

Current photovoltaic solar modules harvest 15- 20% of incoming solar energy, using solar cells such as high-efficiency monocrystalline silicon solar cells. The balance 80 - 85% of incoming solar energy is wasted as waste heat dumped into the environment. Despite this poor harvest efficiency, current solar modules offer simplicity, reliability and low levelized cost of energy (LCOE) and hence are experiencing strong market growth worldwide. The solar energy industry could grow even more rapidly if means were available to double or triple solar energy harvest as a percentage of incoming solar energy, while also avoiding land costs by moving to cost-effective offshore solar power systems. This paper presents a portfolio of low-cost solar innovations ranging from (i) 'SuperSurya' low-cost rooftop cogeneration modules that provide both electricity and usable heat (for hot water, space heating & swimming pool heating); to (ii) Efficient Concentrating Cogeneration Offshore Solar (ECCOS) Systems that can vary in scale from small private systems to very large systems that provide electricity and district heating / district cooling to coastal cities with zero land use and unprecedented low LCOE for offshore systems; to (iii) ECCOS systems synergistically combined with collocated offshore wind, offshore tidal/ocean current or OTEC systems.

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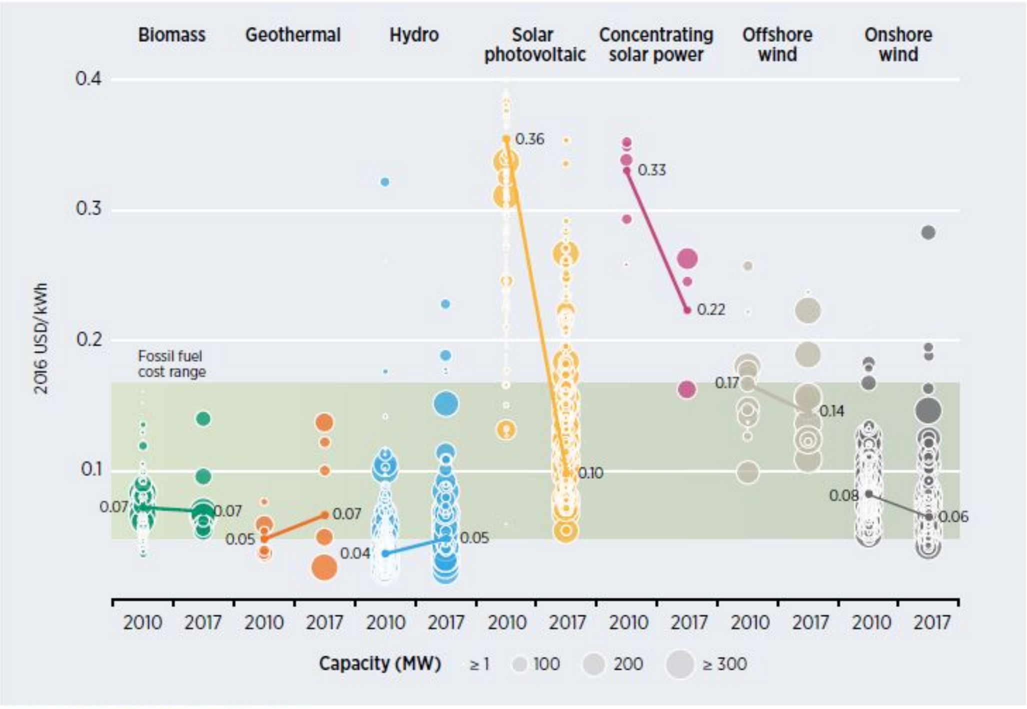
2. Background: Challenge & Opportunity

The challenges of global climate change are well-known in the scientific community, and to some extent across the realm of government leaders and the public at large. One particularly worrisome, but possible worst-case scenario, is that if the global temperature rises by 10° C or more, the entire icecaps of Antarctica and Kalaallit Nunaat would likely melt, submerging one third of humankind living in coastal areas (Zolfagharifard, 2014). As a counterpoint to the existential threat posed by this challenge, the opportunities for solar power are extraordinarily promising, with more than enough potential for solar energy to meet 100% of humankind's energy needs. The forecast 2040 mean rate of global energy consumption is estimated at 27,300 gigawatts (GW), and forecast electricity production at 4,170GW (Energy Information Administration, 2016). By contrast, the total solar radiation that falls on the Earth's surface is ~ 90,000,000 GW. Recoverable solar power is greater than 1,000,000 GW and thus far exceeds humankind's current needs or needs into the foreseeable future.

While recoverable solar power is greater than 1,000,000 GW and thus far exceeds humankind's current needs, accelerated implementation of solar energy systems to replace fossil fuel energy systems will require that renewable systems levelized cost of energy (LCOE) must be competitive or lower than fossil fuel systems (Fig. 1). A key reason for the rapid growth of simple, reliable photovoltaic systems such as basic solar panels, is that their LCOE has been rapidly reduced, dropping from 36 cents/kW-hr in 2010 to 10 cents/kW-hr in 2017.

Figure ES.1 Global levelised cost of electricity from utility-scale renewable power generation technologies, 2010-2017



Source: IRENA Renewable Cost Database.

Note: The diameter of the circle represents the size of the project, with its centre the value for the cost of each project on the Y axis. The thick lines are the global weighted average LCOE value for plants commissioned in each year. Real weighted average cost of capital is 7.5% for OECD countries and China and 10% for the rest of the world. The band represents the fossil fuel-fired power generation cost range.

Fig. 1: Levelized Cost of Energy (LCOE) Comparisons (IRENA, 2017)

Some limitations of simple solar panels include their relatively poor efficiency, with typical silicon solar panels only converting 15 to 20% of solar energy into useful electric energy, as well as fundamental difficulty in meeting base load needs due to relatively low capacity factors, with solar power generation stopping at night and reducing during periods of cloud cover. Innovations to improve solar harvest and enable further reductions of LCOE will be vital to enable further acceleration of cost-effective solar energy systems to serve both electric power and heating/cooling needs around the World.

3. Cost Reduction Leveraging Innovations in Low-Cost CPV with Cogeneration

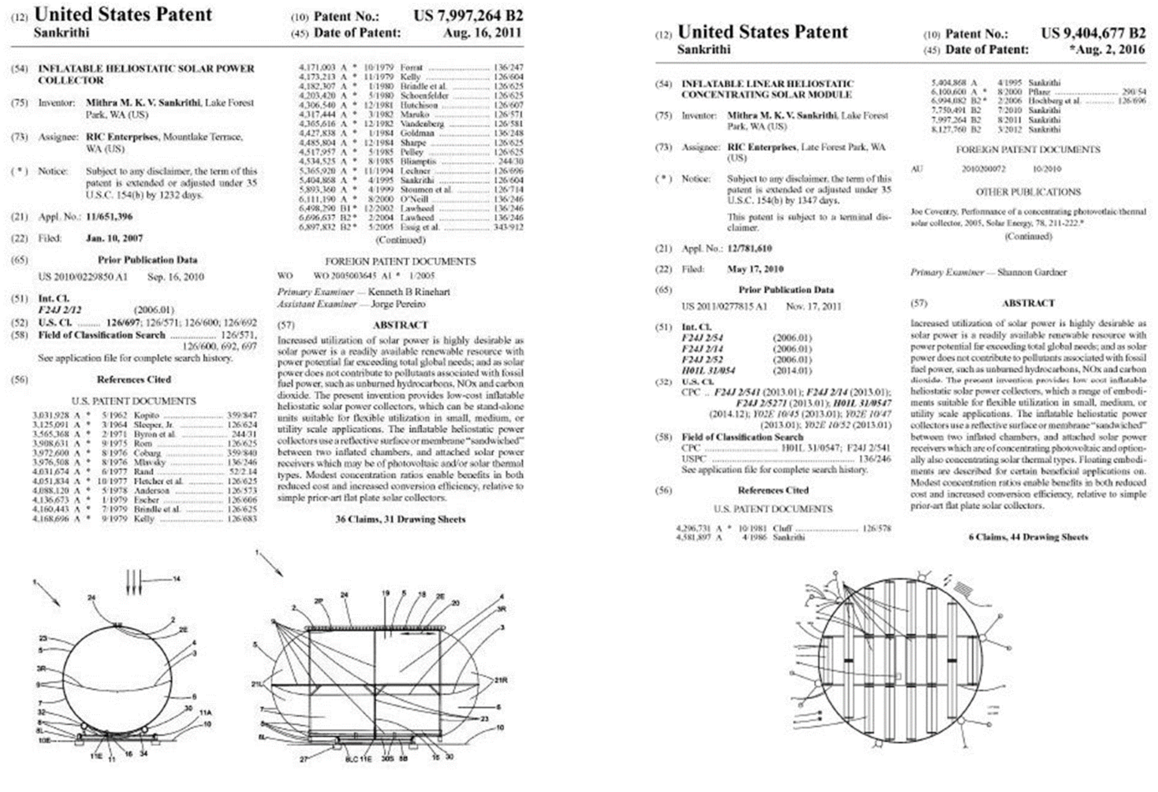
In addition to continued evolutionary improvements in efficiency and cost of photovoltaic solar modules, achievement of further significant reductions in levelized cost of energy (LCOE) will require additional cost-reduction enabling innovations across several areas. Some key high-leverage cost-reduction enablers are:

1) Use of a low-concentration concentrating photovoltaic (CPV) subsystem, with 5 to 10 suns concentration to enable more electricity from each photovoltaic cell:
   Enables kWe / Sq.m. of PV receiver to increase by ~ 400% to 800%
   Enables PV receiver cost / kWe to decrease ~ 70% to 80%
   Enables continued use of nonexotic silicon photovoltaics
   Feasible with simple & robust tracking and cooling subsystems

2) Use of a low-cost inflatable concentration subsystem with a framed membrane linear concentrating reflector with an inflatable upper volume and ETFE transparent membrane protective cover
   Relative to a typical steel & toughened glass concentration mirror:
   Enables concentration subsystem weight & capital cost reduction of ~ 50% to 80%
   Enables concentration subsystem cleaning & repair cost reduction of ~ 60% to 90%

3) CPV liquid cooling that also transfers usable heat for hot water, home or building space heating, swimming pool heating, or solar cooling using absorption chillers
   Harvested energy increases from ~ 12% - 22% to ~ 60% - 80% of insolation
   Usable heat in kWt can be ~ 300% to 500% added harvest over electricity
   Cogeneration system cost may increase ~ 15% - 30% over pure electric CPV

RIC Enterprises has captured key innovation elements of these high-leverage cost-reduction enablers in two foundational patents (Fig. 2).



(12) **United States Patent**
Sankrithi

(10) **Patent No.:** **US 7,997,264 B2**
(45) **Date of Patent:** **Aug. 16, 2011**

(54) **INFLATABLE HELIOSTATIC SOLAR POWER COLLECTOR**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1232 days.

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(58) **Field of Classification Search** 126/571, 126/600, 692, 697
See application file for complete search history.

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(57) **ABSTRACT**

Increased utilization of solar power is highly desirable as solar power is a readily available renewable resource with power potential far exceeding total global needs; and as solar power does not contribute to pollutants associated with fossil fuel power, such as unburned hydrocarbons, NOx and carbon dioxide. The present invention provides low-cost inflatable heliostatic solar power collectors, which can be stand-alone units suitable for flexible utilization in small, medium, or utility scale applications. The inflatable heliostatic power collectors use a reflective surface or membrane "sandwiched" between two inflated chambers, and attached solar power receivers which may be of photovoltaic and/or solar thermal types. Modest concentration ratios enable benefits in both reduced cost and increased conversion efficiency, relative to simple prior-art flat plate solar collectors.

36 Claims, 31 Drawing Sheets

(12) **United States Patent**
Sankrithi

(10) **Patent No.:** **US 9,404,677 B2**
(45) **Date of Patent:** ***Aug. 2, 2016**

(54) **INFLATABLE LINEAR HELIOSTATIC CONCENTRATING SOLAR MODULE**

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(73) Assignee: **RIC Enterprises**, Late Forest Park, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1347 days.
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(52) **U.S. Cl.**
CPC .. ***F24J 2/541*** (2013.01); ***F24J 2/14*** (2013.01); ***F24J 2/5271*** (2013.01); ***H01L 31/0547*** (2014.12); *Y02E 10/45* (2013.01); *Y02E 10/47* (2013.01); *Y02E 10/52* (2013.01)
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USPC 136/246
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Primary Examiner — Shannon Gardner

(57) **ABSTRACT**

Increased utilization of solar power is highly desirable as solar power is a readily available renewable resource with power potential far exceeding total global needs; and as solar power does not contribute to pollutants associated with fossil fuel power, such as unburned hydrocarbons, NOx and carbon dioxide. The present invention provides low cost inflatable heliostatic solar power collectors, which a range of embodiments suitable for flexible utilization in small, medium, or utility scale applications. The inflatable heliostatic power collectors use a reflective surface or membrane "sandwiched" between two inflated chambers, and attached solar power receivers which are of concentrating photovoltaic and optionally also concentrating solar thermal types. Floating embodiments are described for certain beneficial applications on. Modest concentration ratios enable benefits in both reduced cost and increased conversion efficiency, relative to simple prior-art flat plate solar collectors.

6 Claims, 44 Drawing Sheets

Fig. 2: Foundational Intellectual Property for Some Key Solar Cost-Reduction Innovations

It should be noted that the innovations for cost-reduction are primarily of an applied design and architectural nature, and do not rely on nascent high-technology subsystems that can substantially increase cost and risk.

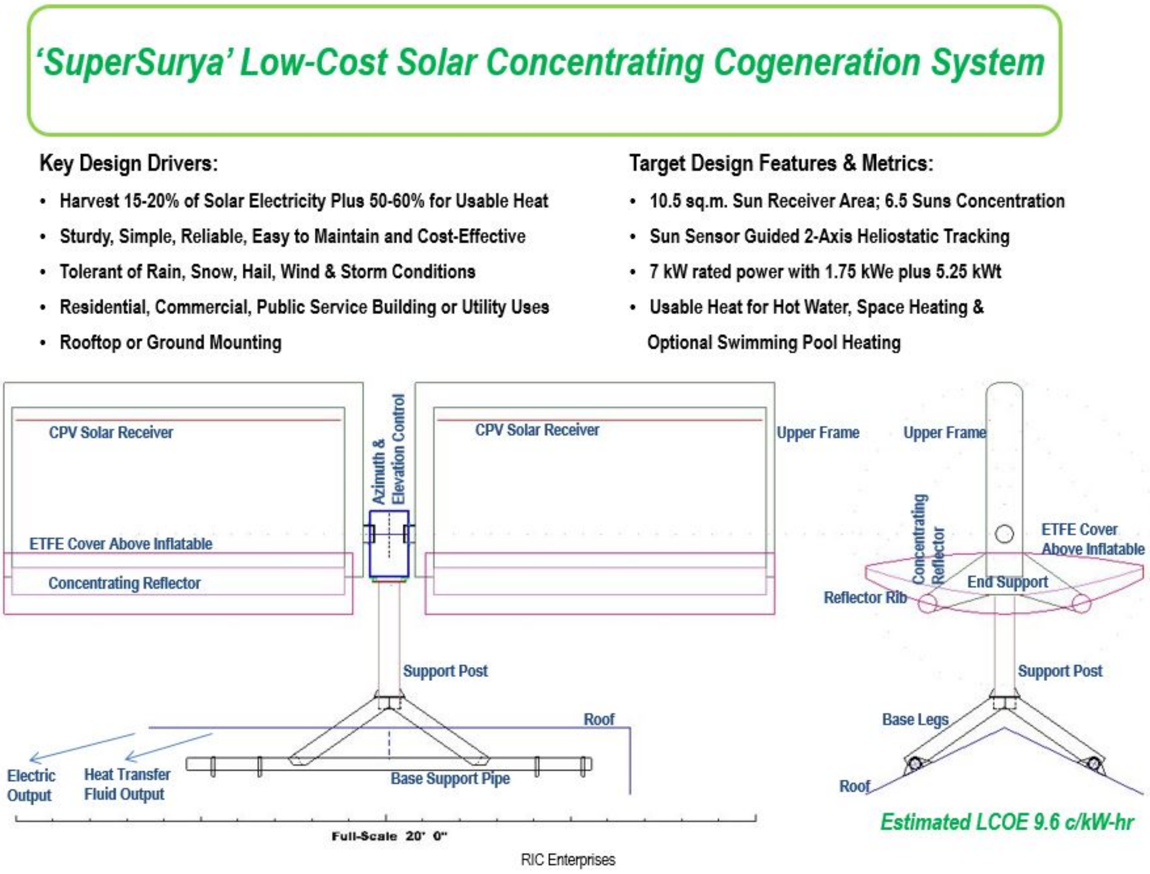
Subsystems are intended to be simple, reliable, and robust. Some of the subsystems that have been tested by RIC Enterprises include:

- Use of a reflective concentrating framed membrane reflector
- Use of a low-cost inflatable structure with a transparent protective weather cover
- Use of an Ethylene Tetrafluoroethylene (ETFE) transparent weather cover that self-cleans in rain
- Use of heliostatic tracking subsystems
- Use of a CPV cooling system
- Demonstration of an inverted-stow protection concept for storm and hail conditions

A representative set of design criteria to integrate the above-described high-leverage cost-reduction enablers into a rooftop low-cost cogeneration system include:

- Size to 1.75 kW electricity plus 5.25 kW usable heating @ 65 – 75° C
- Meet typical home electricity, hot water & space heating needs with 1-2 modules & net-metering
- Length < 19’4” to enable transport in standard 20’ containers
- Low-concentration ratio leverages cost-effective liquid-cooled Si solar cells
- Framed inflatable concentrating reflector modules with ETFE self-cleaning covers
- Modular design for low-cost transportation, installation, maintenance & repair
- Sun-sensor and two-axis actuators for elevation and azimuth control
- Aluminum welded structure for low cost, strength and aesthetics
- Base structure adapts easily for roof or optional ground mounting

An integrated configuration designated ‘SuperSurya’ has been designed responsive to these design criteria, and is illustrated in Fig. 3.



‘SuperSurya’ Low-Cost Solar Concentrating Cogeneration System

Key Design Drivers:

- Harvest 15-20% of Solar Electricity Plus 50-60% for Usable Heat
- Sturdy, Simple, Reliable, Easy to Maintain and Cost-Effective
- Tolerant of Rain, Snow, Hail, Wind & Storm Conditions
- Residential, Commercial, Public Service Building or Utility Uses
- Rooftop or Ground Mounting

Target Design Features & Metrics:

- 10.5 sq.m. Sun Receiver Area; 6.5 Suns Concentration
- Sun Sensor Guided 2-Axis Heliostatic Tracking
- 7 kW rated power with 1.75 kWe plus 5.25 kWt
- Usable Heat for Hot Water, Space Heating & Optional Swimming Pool Heating

Fig. 3: ‘SuperSurya’ Configuration Integrating LCOE Reduction Enablers

It is conservatively estimated that ‘SuperSurya’ can achieve an LCOE of approximately 9.6 cents per kW-hr, or at least 10% lower than conventional simple solar panels, with the following assumptions:

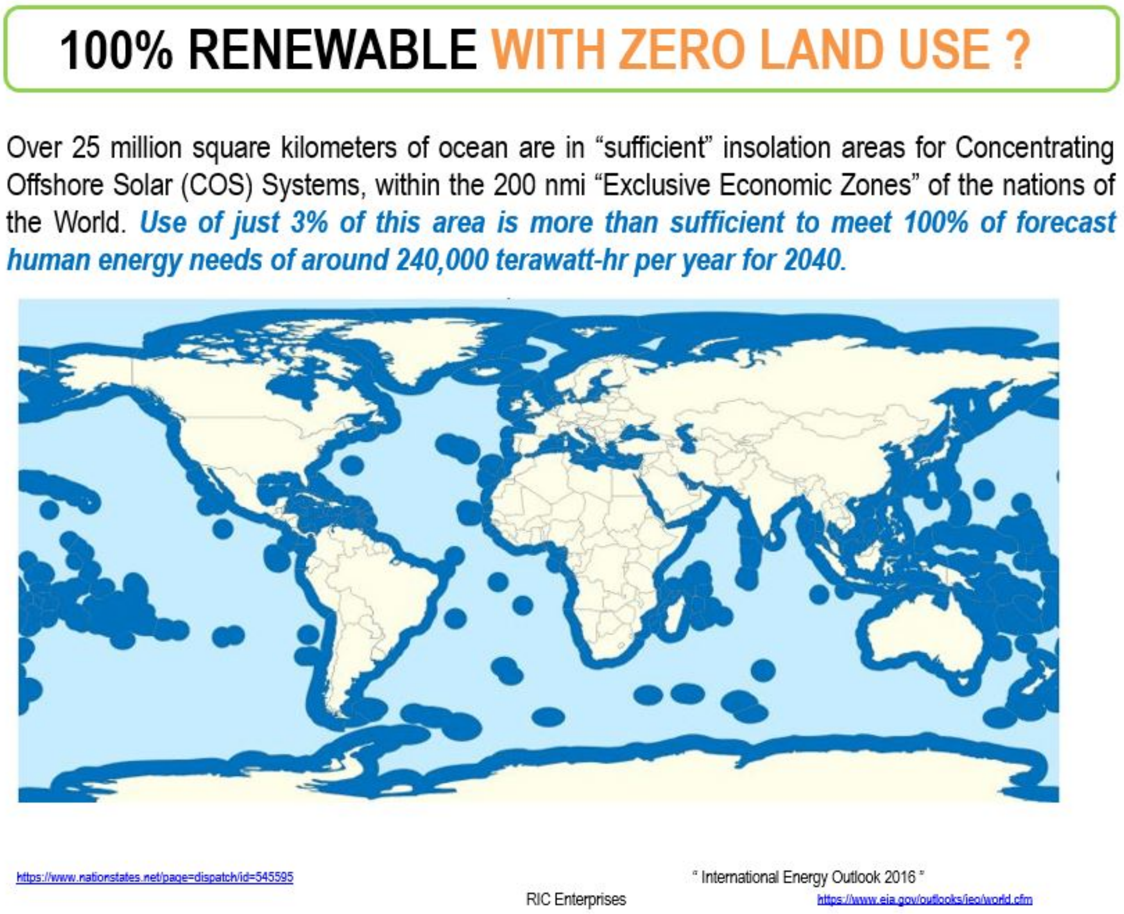
- *75% of harvested energy is usable heat*
- *capital cost up from $2100/kW to $3000/kW*
- *capacity factor up from 18% to 35%*
- *O&M costs triple*
- *Using the NREL Simplified Life Cycle Cost of Energy (LCOE) calculator*

Even more dramatic cost metrics will be possible as these new rooftop cogeneration systems mature, and holistically serve home electricity and heating energy needs, with space heating and hot water heating using 40% and 20% of total home energy, in some typical cases. For homes with swimming pools, the percentage of total energy used for heat increases even more, making cogeneration systems like SuperSurya even more attractive.

4. Efficient Concentrating Cogeneration Offshore Solar (ECCOS) Systems

Utility-scale solar energy systems, whether using PV, CPV, or solar thermal technologies, all have the downside of using large spaces of land that could otherwise potentially be used for a variety of land uses ranging from residential to commercial to industrial to agricultural to natural spaces for plants and animals.

This provides strong motivation for a strategic vision for future cost-effective offshore solar systems, which could potentially meet the entire world's energy needs using waters within the 200 nm Exclusive Economic Zones (EEZs) of the nations of the world (Fig. 4).



100% RENEWABLE WITH ZERO LAND USE ?

Over 25 million square kilometers of ocean are in "sufficient" insolation areas for Concentrating Offshore Solar (COS) Systems, within the 200 nmi "Exclusive Economic Zones" of the nations of the World. ***Use of just 3% of this area is more than sufficient to meet 100% of forecast human energy needs of around 240,000 terawatt-hr per year for 2040.***

https://www.nationstates.net/page=dispatch/id=545595

" International Energy Outlook 2016 "

RIC Enterprises

https://www.eia.gov/outlooks/ieo/world.cfm

Fig. 4: Offshore Solar Potential in Exclusive Economic Zones (EEZs) (Barry, 2016)

Two key cost-reduction enablers associated with offshore solar are:

1) Offshore installation yields elimination or near-elimination of land cost
   Avoided land cost can exceed $2 million per acre, in coastal urban areas

such as the San Francisco Bay area

2) Use of heliostatic azimuth control by rotating an entire floating array rather than rotating individual solar modules

   Number of azimuth control actuators decreases by ~ 50% to 99.9%

   Azimuth control subsystem cost decreases by ~ 40% to 99%

The cost savings associated with offshore solar are, of course, offset in part by needing floatation systems as well as underwater transmission systems.

Some offshore solar systems have already been implemented in a few areas such as Japan with a 13.7 MW floating solar photovoltaic plant on a reservoir (Brown, 2018) and China with a 150 MW floating PV plant in a $151 million project (Kenning, 2017), that avoid land cost but do not include the other cost reduction enablers noted above. These Japan and China offshore systems harvest sunlight to produce electricity, but their LCOE is expected to be higher than terrestrial installations in low land cost areas such as desert areas, because of the floatation and transmission systems needed.

To accelerate implementation and enable more cost-effective widespread deployments of offshore solar, it would be highly beneficial to apply the *low-cost* and *cogeneration* features of the SuperSurya system, to offshore solar power systems as well. One particular vector of this opportunity would be to replace land-based solar district heating systems, such as the strongly growing district heating systems in Denmark (Dansk Fjernvarme, 2018), with offshore solar cogeneration systems that can provide both *electricity* and *district heating* or *district cooling* while avoiding land costs.

Key economic drivers for Efficient Concentrating Cogeneration Offshore Solar (ECCOS) System include the fact that the majority of global insolation falls offshore; offshore design avoids land use, and many opportunities for synergies exist for cogeneration of electricity, usable heat, desalination, etc. The scalability of ECCOS systems is particularly important as a large-scale growth enabler, with customers including:

- waterfront homeowners
- public service or commercial buildings
- agricultural or industrial customers
- waterfront airports like New York JFK, San Francisco SFO & many more
- waterfront cities or counties, with electric as well as district heating & district cooling opportunities

At the smallest end of the ECCOS opportunities lie "Mini-Scale ECCOS Systems," which leverage many of the SuperSurya low-cost enabling features in a simple, robust design of an innovative floating system as shown in Fig. 5. Mini-Scale ECCOS Systems can be used beneficially for a wide variety of urban and rural customer classes. Key attributes of the Mini-Scale Efficient Concentrating Cogeneration Offshore Solar Systems include:

- 5 kWe + cogenerated 10 kWt
- Suitable for grid-connected or off-grid applications
- CPV electricity plus usable heat for a solar hot water tank, solar building space heating & swimming pool heating
- ***Efficient, cost-effective, no land use***
- Rain or Spray wash to clean
- Solar Modules inverted stow for storm survival
- Modular design for easy replacement of modules

LCOE is estimated at 10.6 cents per kW-hr, using the NREL LCOE calculator.

Mini-Scale ECCOS Systems can also be combined in an array surrounded by a security and wave blocking perimeter floating fence. An array of 20 Mini-Scale ECCOS Systems could generate 100kWe plus 200 kWt of usable heat, and could be ideal for a variety of community, commercial and small industrial users. LCOE is estimated at 9.6 cents per kW-hr.

Scaling up from Mini-Scale ECCOS Systems, the next scale is called Small-Scale, and the next Medium-Scale. A Medium-Scale Efficient Concentrating Cogeneration Offshore Solar System including desalination is illustrated in Fig. 6. Desalination systems can provide a very valuable synergistic benefit with cost-effective desalinated water for desert or dry climate coastal cities or communities. Advantages of low temperature desalination include low cost through use of modest temperature heat sources, low environmental heat losses, low corrosion and scaling rate, and flexibility and reliability (Gude, 2007).

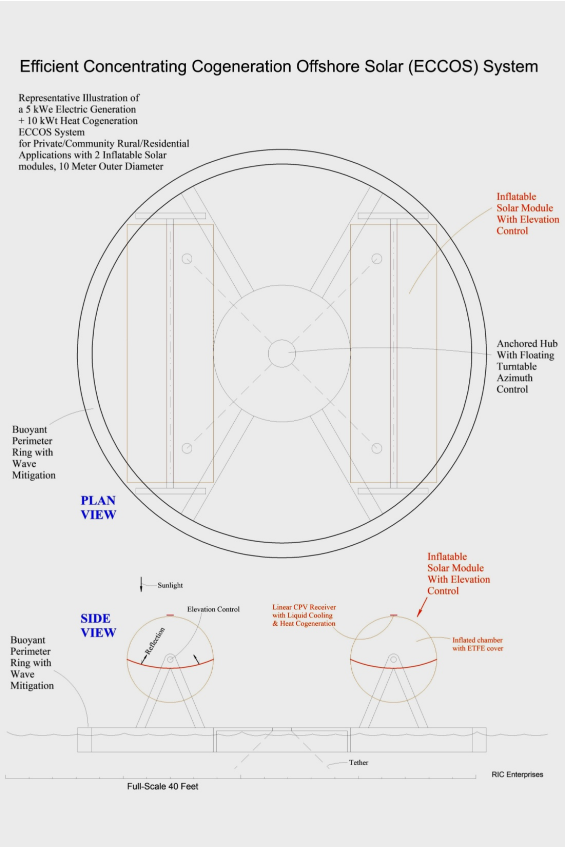
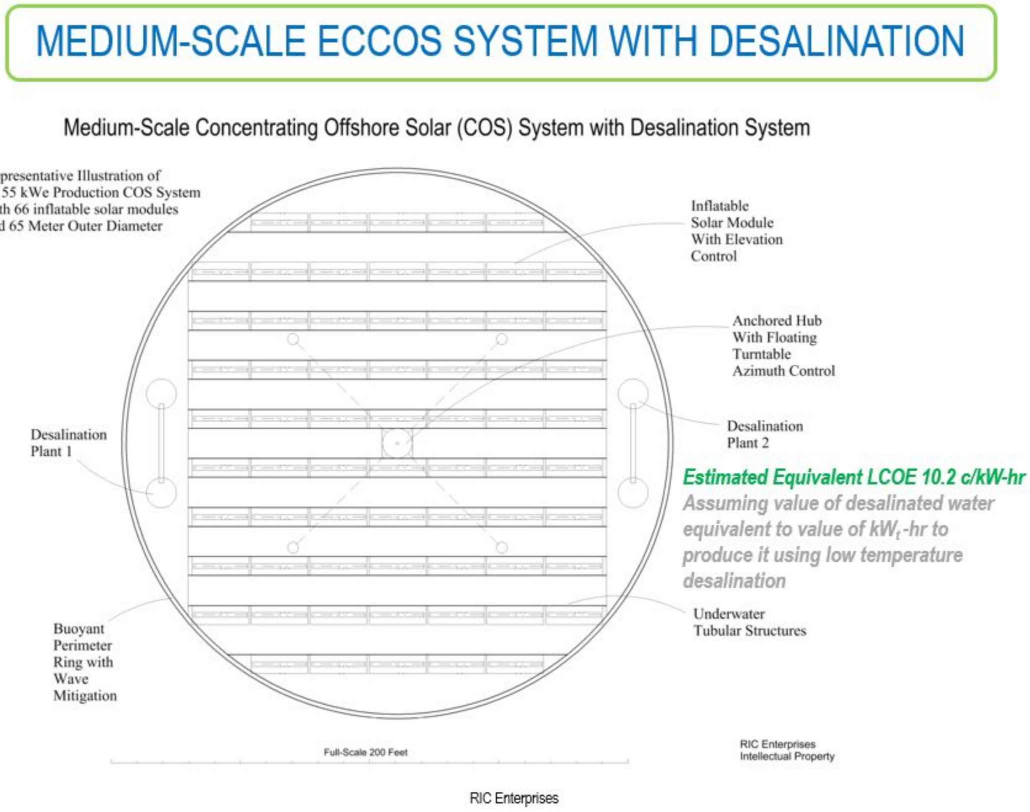


Fig. 5: Mini-Scale ECCOS System



MEDIUM-SCALE ECCOS SYSTEM WITH DESALINATION

Medium-Scale Concentrating Offshore Solar (COS) System with Desalination System

Representative Illustration of a 155 kWe Production COS System with 66 inflatable solar modules and 65 Meter Outer Diameter

Estimated Equivalent LCOE 10.2 c/kW-hr

Assuming value of desalinated water equivalent to value of kW_t-hr to produce it using low temperature desalination

Fig. 6: Medium-Scale ECCOS System with Low-Temperature Desalination

The next major scale for ECCOS systems comprises Mega-Scale ECCOS Systems, as illustrated in Fig. 7. Mega-Scale Efficient Concentrating Cogeneration Offshore Solar Systems present a unique innovative configuration that is ideally suited to deliver a combination of electric power along with district heating and cooling for waterfront cities and communities, with unprecedented offshore renewable system economics and LCOE. Mega-Scale ECCOS Systems can also include a Rankine or Steam Cycle Subsystem to provide solar thermal based supplementary electric power. The Rankine Cycle subsystem could leverage geothermal energy turbines with a 130^{o} C heat source, or conversely more high-technology higher thermodynamic efficiency subsystems leveraging direct steam generation (DSG) at up to 600^{o} C.

The ideal suitability of Mega-Scale ECCOS Systems can be understood with much greater clarity by considering a specific example application, shown in Fig. 8 for the San Francisco Bay area with its very large energy needs, very large population, and very high land values. ECCOS Systems could meet 100% of Bay Area energy needs with just 2% of the Bay water area!

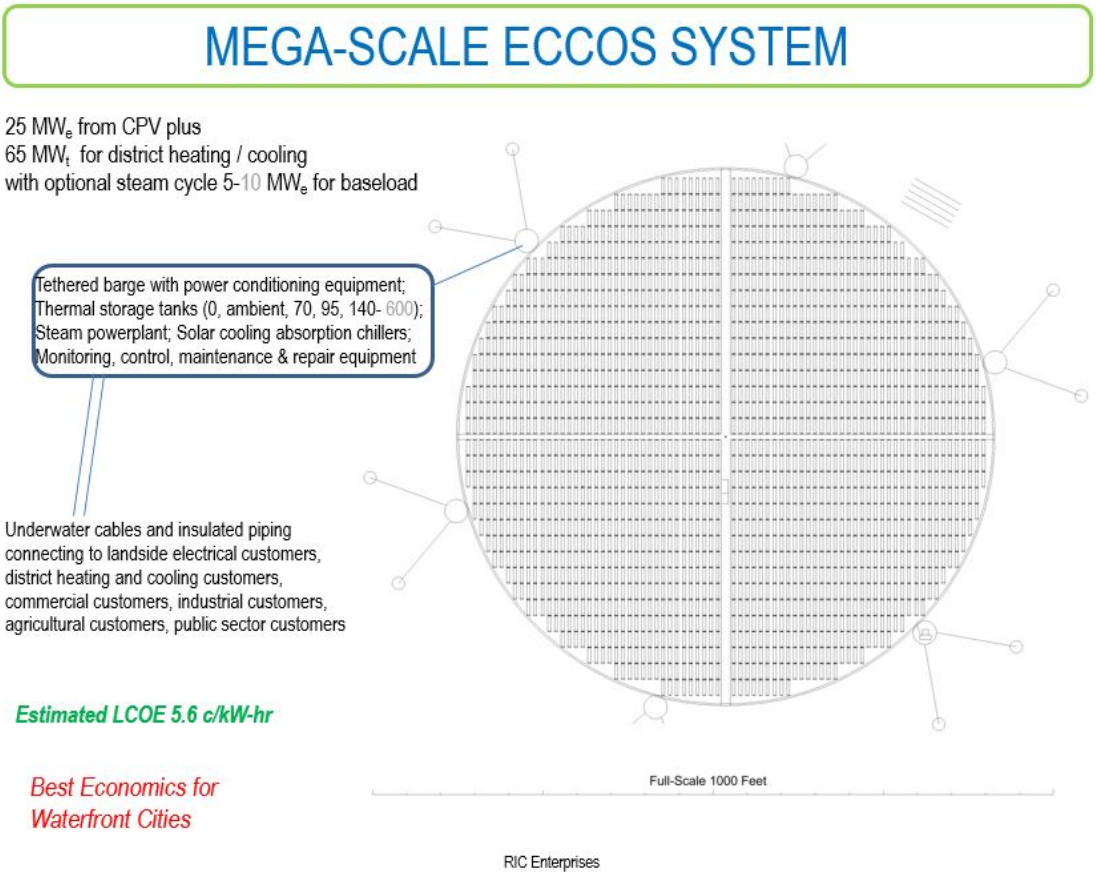
A few other examples of well-suited applications for Mega-Scale ECCOS Systems include the urban areas associated with Salt Lake City, Chicago, Orlando and New York to name just a few specific examples. The Great Salt Lake in Utah is an ideal location with a freeze-resistant salt water lake in a location with a cold winter, where district heating would be highly beneficial. Chicago would also greatly benefit from winter district heating, but because Lake Michigan freezes in the winter, the ECCOS Systems will need a perimeter ring of unfrozen water that can be achieved using adaptations of current freeze-prevention technologies using water bubblers or water circulators. Orlando has many lakes suitable for ECCOS Systems that can enable the city to achieve its ambitious 100% renewable goals, and the ECCOS Systems can provide both electricity and synergistic district cooling to meet Orlando needs, leveraging ammonia-water absorption chiller technologies that are well-known and well-proven. For New York, a great many suitable salt water locations exist for Mega-Scale ECCOS Systems that can provide electricity plus hot water as well as district heating and cooling as needed in different seasons. Skyscrapers, apartment blocks, commercial and industrial buildings, and all three major New York area airports could benefit from 100% renewable electricity, heat and cooling, with Mega-Scale ECCOS Systems and some measure of storage for both electricity and heat.

Many international locations would also greatly benefit from the combination of low LCOE, zero land use, and synergistic provision of district heating and cooling as required, and a few examples include Rio de Janeiro, Istanbul, Mumbai, Hong Kong, Tokyo and Singapore. Note that the authorities in Singapore are already considering offshore solar in the seas off this leading city-state of Southeast Asia. The ECCOS System provides a more cost effective innovation with multiple synergistic benefits, and should prove to be a very attractive option for Singapore's future success and economic growth.

An even larger scale version of the Efficient Concentrating Cogeneration Offshore Solar System comprises Ultra-Large Open Ocean Utility-Scale ECCOS System, as illustrated in Fig. 9 below. Ultra-large systems are likely to be located in Exclusive Economic Zone (EEZ) waters within 200 nautical miles of the shore, but too far from shore for economic direct transport of heat for district heating. On the other hand, at different geographic locations it would be beneficial for these to synergistically produce combinations of: (i) electricity from CPV, (ii) additional electricity from a Rankine Cycle solar thermal subsystem, (iii) desalinated water, and (iv) solar powered hydrogen generation from the ocean water, where the hydrogen can be used locally for night generation as well as shipped to shore either as compressed gas, liquid hydrogen, or metal hydrides, and subsequently used in a hydrogen economy subsystem of a green economy. Open ocean installations will require larger and more robust wave barriers for ocean waves, and damage prevention modes for hurricanes, typhoons, cyclones and tsunamis.

Many global applications of Ultra-Large Utility-Scale Efficient Concentrating Cogeneration Offshore Solar Systems can be in bays or in the open ocean, including the Pacific off California, the Gulf of Mexico, the Mediterranean and Black and Red Seas, and the Arabian Sea offshore from India and South China Sea offshore from China and the nations of Southeast Asia. These can be instrumental in a global paradigm-shift to leverage offshore solar to meet worldwide needs with near-zero carbon footprint and near-zero land use !

In view of the fact that in many offshore locations, there are other renewable energy sources besides solar energy, it can also be highly cost-effective in these particular locations, to share common subsystems such as anchoring subsystems and shore connection subsystems (e.g., electrical power and insulated heat transfer piping) across multiple different but synergistic renewable energy offshore systems.



MEGA-SCALE ECCOS SYSTEM

25 MW_e from CPV plus
65 MW_t for district heating / cooling
with optional steam cycle 5-10 MW_e for baseload

Tethered barge with power conditioning equipment;
Thermal storage tanks (0, ambient, 70, 95, 140- 600);
Steam powerplant; Solar cooling absorption chillers;
Monitoring, control, maintenance & repair equipment

Underwater cables and insulated piping
connecting to landside electrical customers,
district heating and cooling customers,
commercial customers, industrial customers,
agricultural customers, public sector customers

Estimated LCOE 5.6 c/kW-hr

*Best Economics for
Waterfront Cities*

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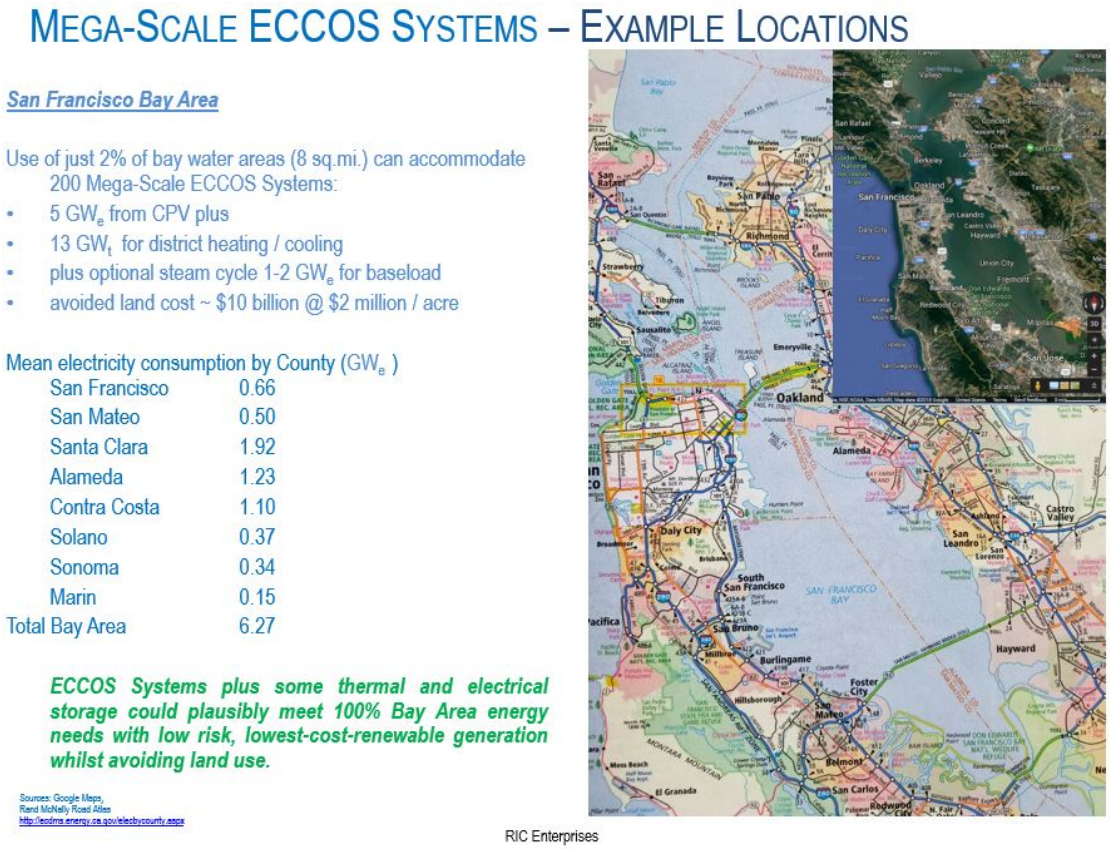
Fig. 7: Mega-Scale ECCOS System Enables Cost-Effective Electricity + District Heating / Cooling



MEGA-SCALE ECCOS SYSTEMS – EXAMPLE LOCATIONS

San Francisco Bay Area

Use of just 2% of bay water areas (8 sq.mi.) can accommodate 200 Mega-Scale ECCOS Systems:

- 5 GW_e from CPV plus
- 13 GW_t for district heating / cooling
- plus optional steam cycle 1-2 GW_e for baseload
- avoided land cost ~ $10 billion @ $2 million / acre

Mean electricity consumption by County (GW_e)

San Francisco	0.66
San Mateo	0.50
Santa Clara	1.92
Alameda	1.23
Contra Costa	1.10
Solano	0.37
Sonoma	0.34
Marin	0.15
Total Bay Area	6.27

ECCOS Systems plus some thermal and electrical storage could plausibly meet 100% Bay Area energy needs with low risk, lowest-cost-renewable generation whilst avoiding land use.

Sources: Google Maps,
Rand McNally Road Atlas
http://ecdms.energy.ca.gov/elecbycounty.aspx

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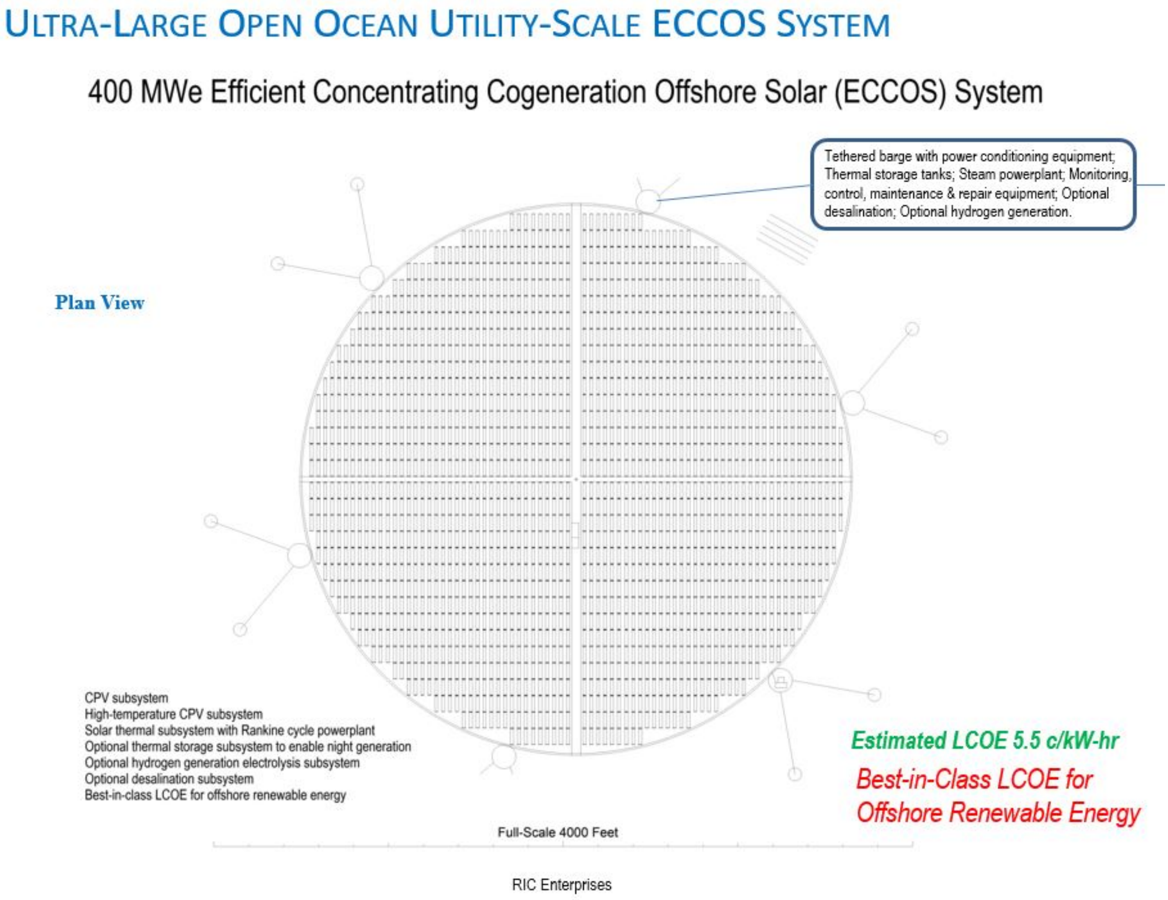
Fig. 8: San Francisco Bay Area Application for Mega-Scale ECCOS Systems



ULTRA-LARGE OPEN OCEAN UTILITY-SCALE ECCOS SYSTEM

400 MWe Efficient Concentrating Cogeneration Offshore Solar (ECCOS) System

Tethered barge with power conditioning equipment; Thermal storage tanks; Steam powerplant; Monitoring, control, maintenance & repair equipment; Optional desalination; Optional hydrogen generation.

CPV subsystem
High-temperature CPV subsystem
Solar thermal subsystem with Rankine cycle powerplant
Optional thermal storage subsystem to enable night generation
Optional hydrogen generation electrolysis subsystem
Optional desalination subsystem
Best-in-class LCOE for offshore renewable energy

Estimated LCOE 5.5 c/kW-hr

Best-in-Class LCOE for Offshore Renewable Energy

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Fig. 9: Ultra-Large Utility-Scale ECCOS System

To be more specific, in order to achieve both increased capacity factor and even more LCOE reduction relative to best-in-class utility-scale ECCOS Systems, these ECCOS Systems can, in selected geographic locations, be synergistically integrated with:

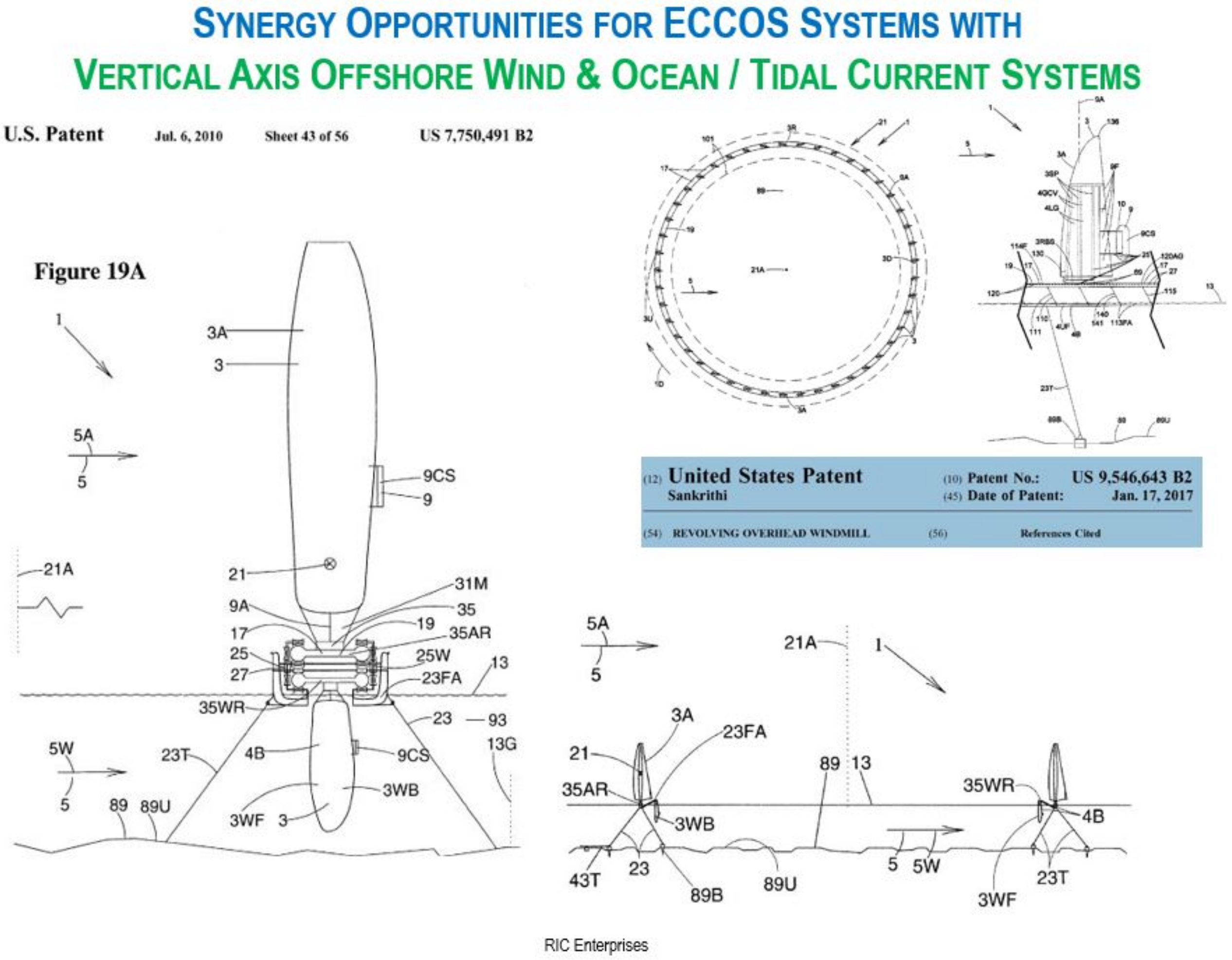
Offshore wind energy technologies
Ocean and tidal current technologies
Ocean thermal energy conversion (OTEC)
Transmission technologies including high voltage / superconducting power lines
    and insulated piping for district heating and cooling
Storage technologies including thermal storage, phase change storage, seasonal storage,
    batteries, hydrogen, pumped hydro, etc.

A few foundational innovations in very large diameter, vertical axis offshore wind and hydrokinetic renewable energy harvesting devices, are captured in RIC Enterprises patents noted in Fig. 10 below, and these can be easily combined with an ECCOS System to harvest solar power in an inner circle within the very large diameter ring of the wind and hydrokinetic harvesting system. The multiple systems can share underwater tethering systems as well as energy transmission systems to the shore.

As a highly promising example of where Efficient Concentrating Cogeneration Offshore Solar (ECCOS) Systems could be synergistically combined and integrated with tidal current and offshore wind harvesting systems, the Bay of Fundy separating Nova Scotia from New Brunswick and Maine, offers tremendous potential with its world-class tidal range combined with healthy wind and solar potential as well.

In a corresponding vein, the extraordinary power of the Gulf Stream ocean current flowing north along the coast of Florida, Georgia and the Carolinas offers a unique opportunity to synergistically combine the power of the Sun, the wind, and the ocean current with ECCOS systems integrated with very large diameter vertical axis wind and water current harvesting systems.

Another synergistic opportunity is to combine ECCOS Systems with Ocean Thermal Energy Conversion (OTEC) systems in regions where deep cold water is available, such as offshore from Hawaii. The temperature differential between the heated CPV cooling fluid and the pumped up deep water "cold sink" will enable greater thermodynamic cycle efficiency than for either the solar thermal subsystem of the ECCOS system by itself, or a stand alone OTEC by itself. Offshore from Hawaii, integration with an offshore wind system is also an attractive and very likely beneficial synergistic opportunity. These synergistic opportunities can be instrumental in helping Hawaii achieve its ambitious 100% renewable goals while minimizing land use.



SYNERGY OPPORTUNITIES FOR ECCOS SYSTEMS WITH
VERTICAL AXIS OFFSHORE WIND & OCEAN / TIDAL CURRENT SYSTEMS

U.S. Patent Jul. 6, 2010 Sheet 43 of 56 US 7,750,491 B2

Figure 19A

(12) **United States Patent**
Sankrithi
(10) Patent No.: US 9,546,643 B2
(45) Date of Patent: Jan. 17, 2017
(54) REVOLVING OVERHEAD WINDMILL
(56) References Cited

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Fig. 10: Offshore Wind & Hydrokinetic Very Large Diameter Vertical-Axis Systems

Based on the several examples outlined above, it can be concluded that Efficient Concentrating Cogeneration Offshore Solar (ECCOS) Systems have extraordinary potential to play a highly beneficial, cost-effective and pivotal role in enabling many cities and other jurisdictions with 100% renewable energy goals, to achieve those ambitious and challenging goals. RIC Enterprises looks forward to collaborating with other members of ASES, ISES and the renewable energy community in enabling a cost-effective green future for our kids, grandkids and generations to come.

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