



National Space Society

MAY 25 - 29, 2017

ISDC

INTERNATIONAL SPACE
DEVELOPMENT CONFERENCE

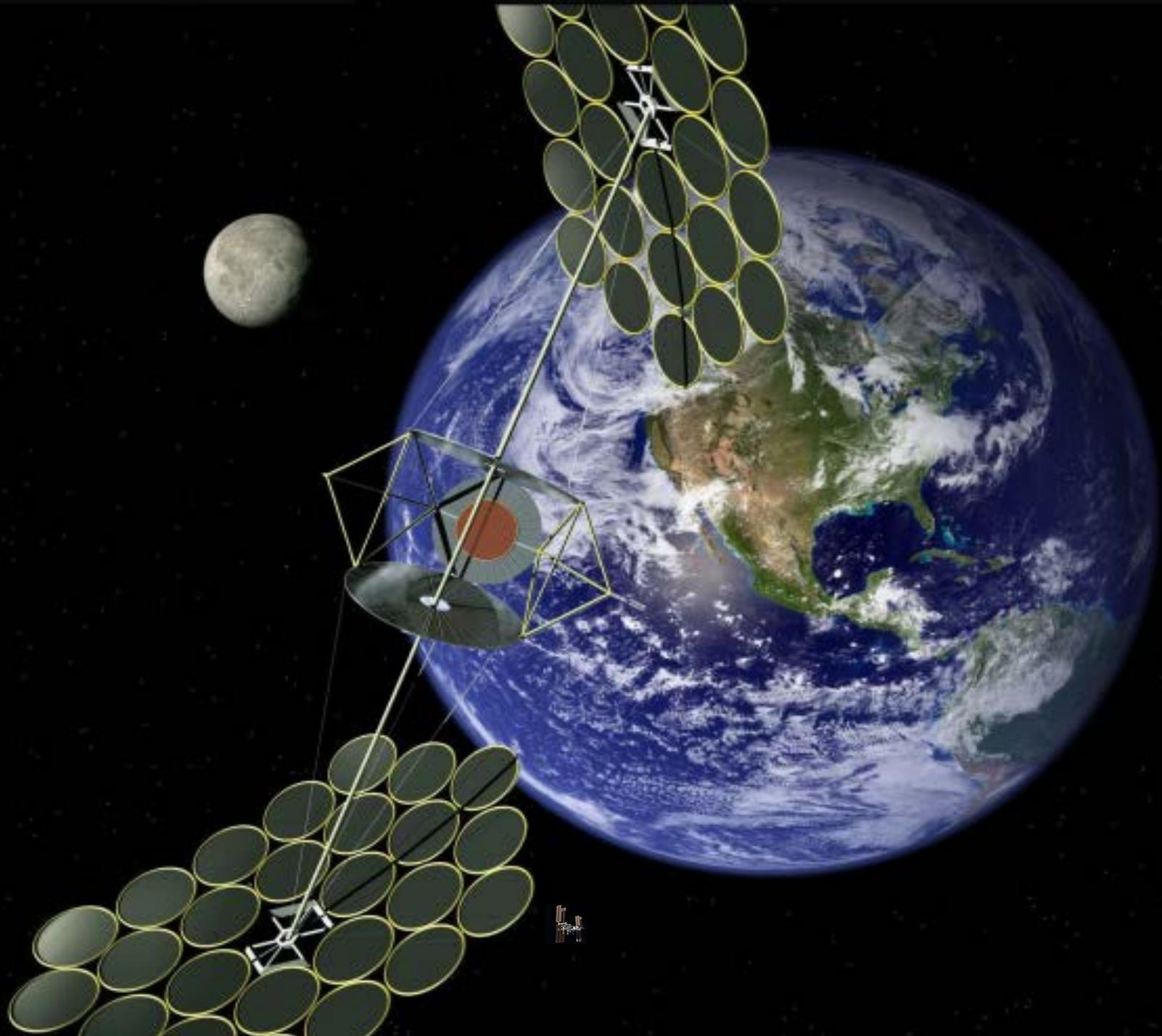
Space Solar Power

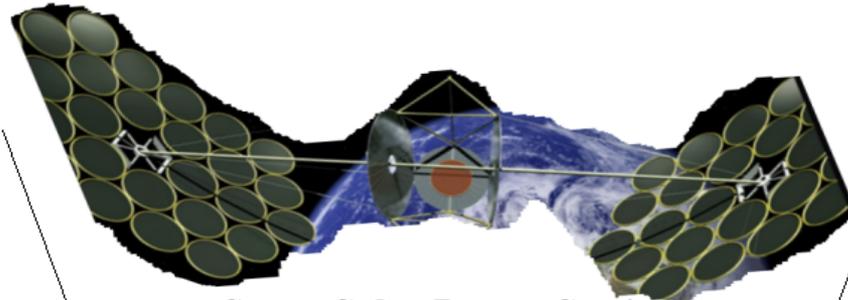
When, Where, Who, Why and How?

Darel Preble, Space Solar Power Institute

**UNION STATION HOTEL
ST. LOUIS, MO**







Space Solar Power Station
diameter= ~ 12 kilometers
altitude= 35,800 km

Since a Space Solar Power Station
would be 90 times farther away and
it is about 90 times greater diameter
it would subtend the same angle
and would be about the same size
and brightness as the ISS to
an observer on Earth.



Intl. Space Station
diameter=131.2 meters
altitude= ~400 km

Energy

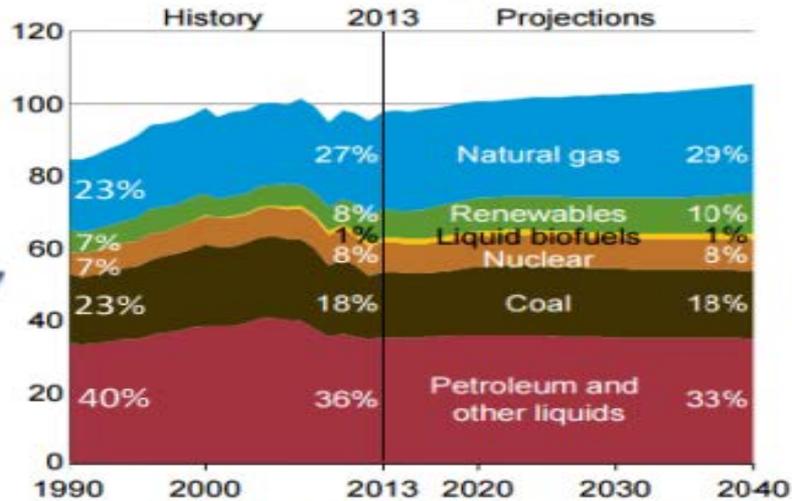


Figure 1. U.S. primary energy consumption by fuel, 1990-2040 (quadrillion Btus / year)
Source: EIA AEO2015 Reference case

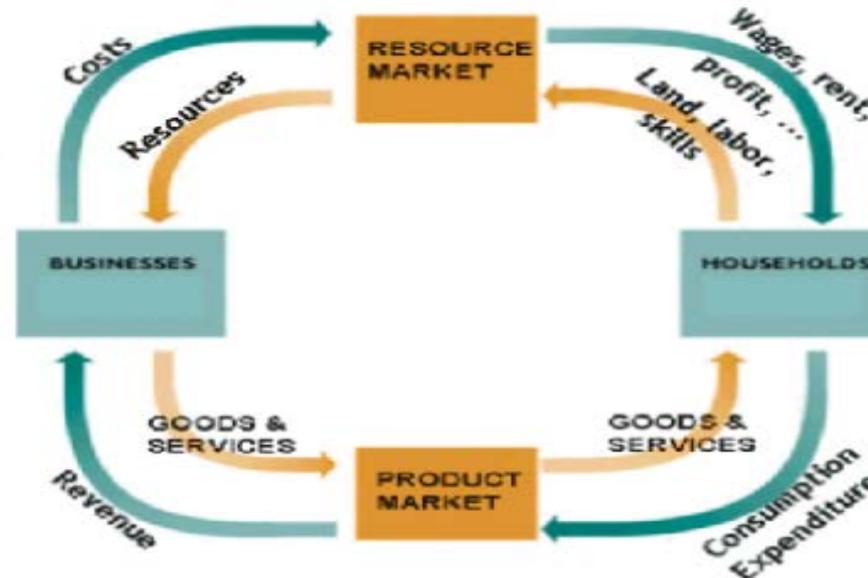
Environment



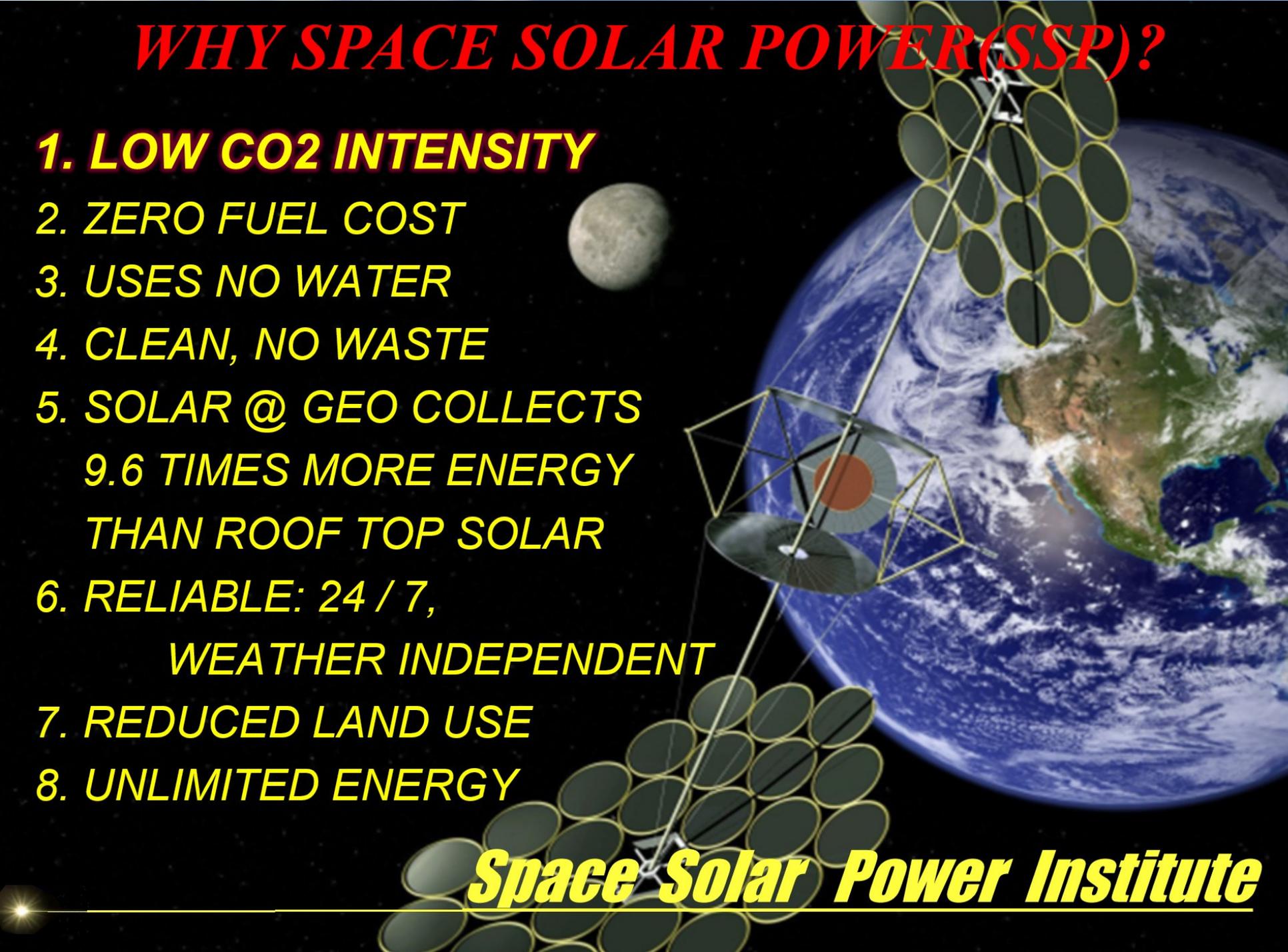
Salt Marsh, the most productive agricultural land known, nursery for shrimp, crab, fish, etc.,
Courtesy: University of Georgia

Space Solar Power Institute

Economy



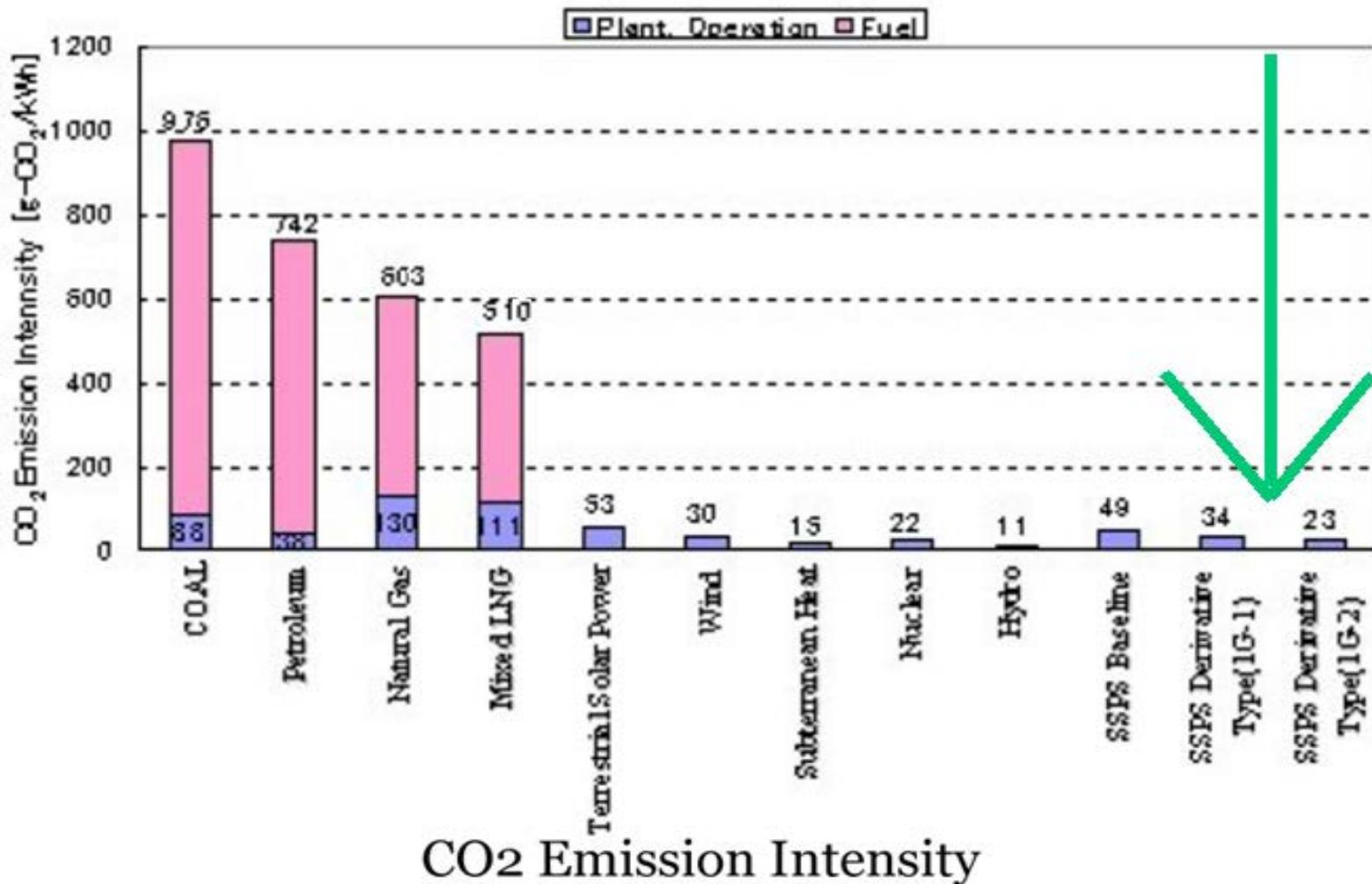
WHY SPACE SOLAR POWER(SSP)?

A satellite with large solar panels is shown in space, orbiting Earth. The Earth is visible in the background, along with the Moon. The satellite has a central body with a red and grey circular target and two large arrays of solar panels extending outwards.

- 1. LOW CO2 INTENSITY***
- 2. ZERO FUEL COST***
- 3. USES NO WATER***
- 4. CLEAN, NO WASTE***
- 5. SOLAR @ GEO COLLECTS
9.6 TIMES MORE ENERGY
THAN ROOF TOP SOLAR***
- 6. RELIABLE: 24 / 7,
WEATHER INDEPENDENT***
- 7. REDUCED LAND USE***
- 8. UNLIMITED ENERGY***

Space Solar Power Institute

Space Solar Power (SSP) has Low CO₂ emission intensity:



Source: JAXA - www.usef.or.jp/english/f3_project/frame_3.html

Looking Back

"The world has made no progress over the past 20 years in reducing the carbon content of its energy supplies, despite over \$2 trillion of investment into renewable-energy projects such as wind and solar power."

- "[Scant Gains Made on CO2 Emissions, IEA Says, WSJ](#)

Instead - Global CO₂ levels continue to increase more rapidly.



#1 Reliability

Energy Return On Investment (**EROI**) = how many BTU's of energy are brought to market per BTU invested.

SSP has essentially zero fuel cost for power generation - a prime advantage for SSP. By tapping the sun directly, SSP is expected to be lower in cost (EROI), than anything else on the energy horizon. Next Figure shows EROI for various power generation plants.

#2 Environmental Regulation

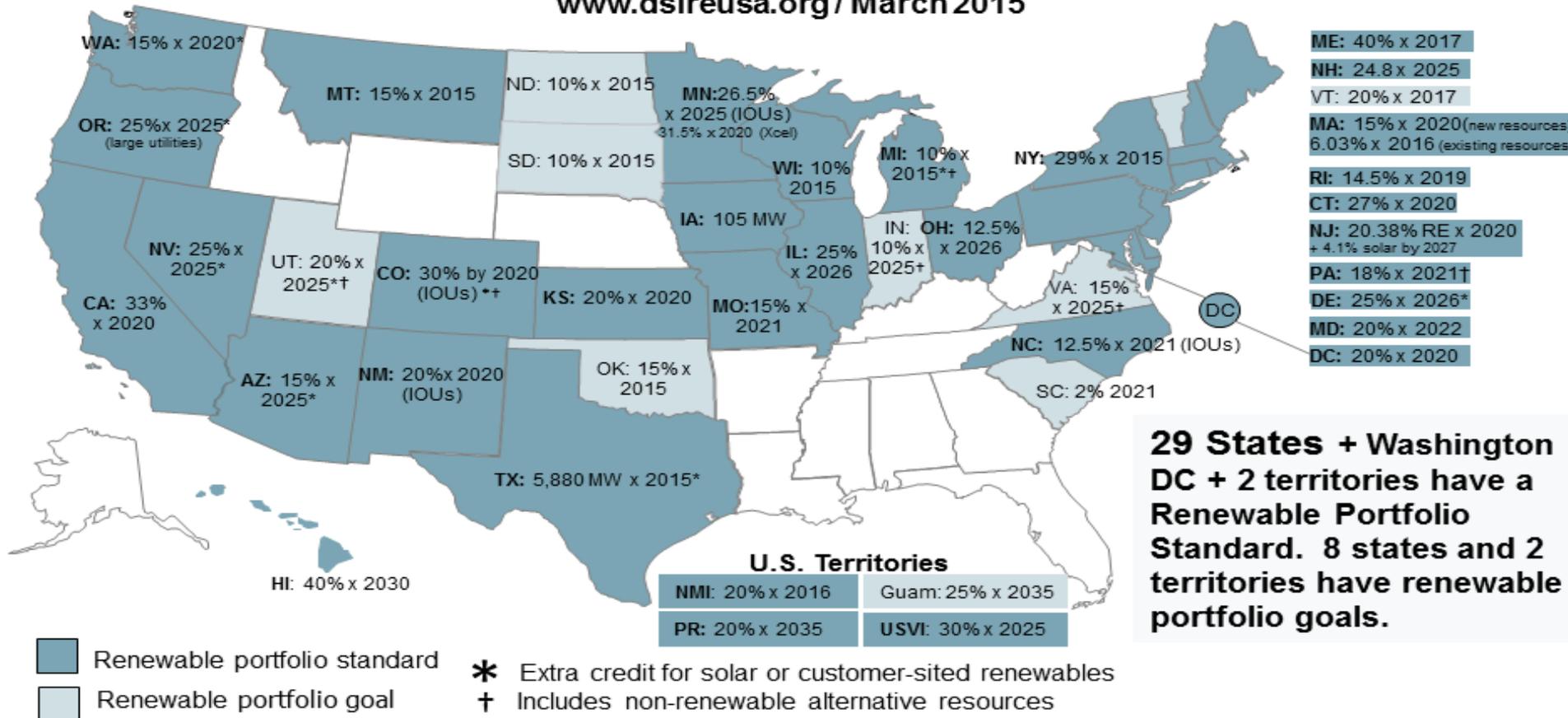


U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy

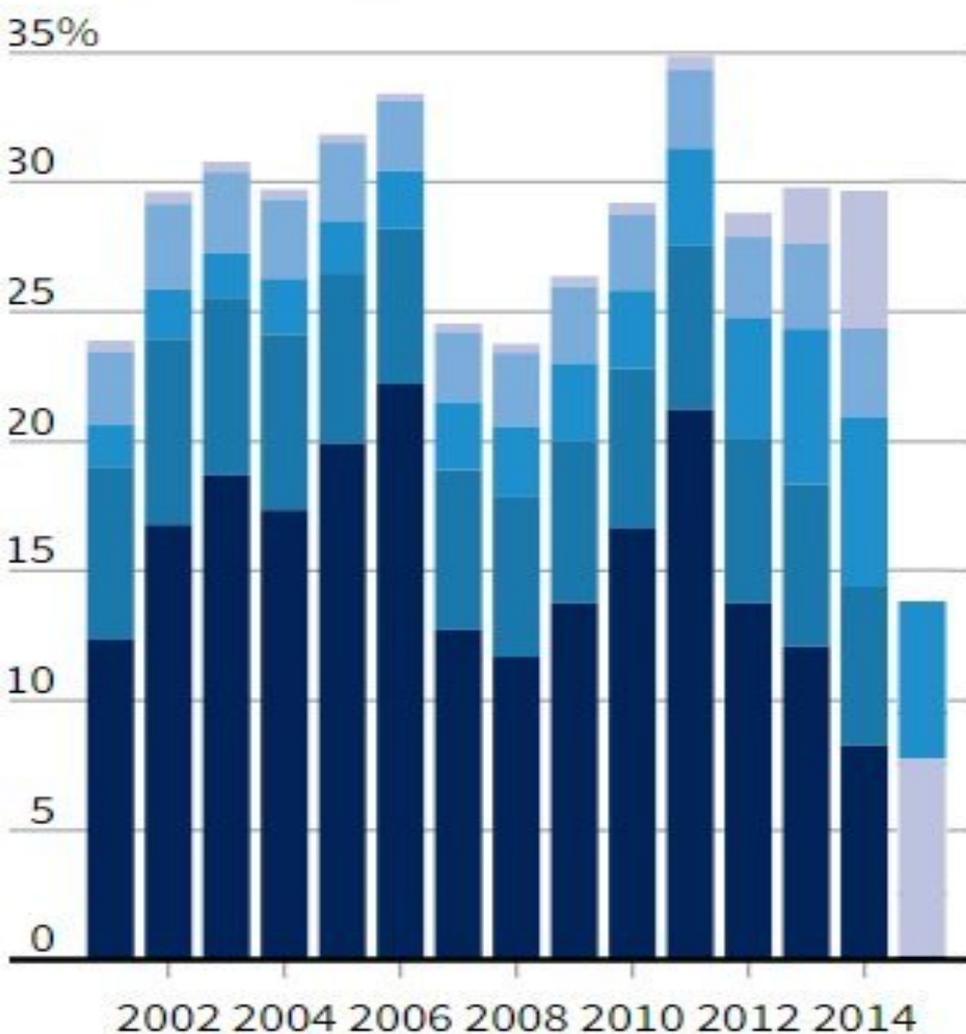
Renewable Portfolio Standard Policies

www.dsireusa.org / March 2015



RENEWABLE ENERGY IN-STATE ELECTRIC GENERATION*

As a percentage of total



- Solar
- Biomass
- Wind
- Geothermal
- Hydro

California's approaching
RPS CRUNCH

14% of 2015 CA generation was from non-dispatchable sources. Typical grid spinning reserve levels range from 10-15%, which backs up unplanned drops in generation.

*Includes biomass, geothermal, nuclear, large hydro, small hydro, solar PV, solar thermal and wind

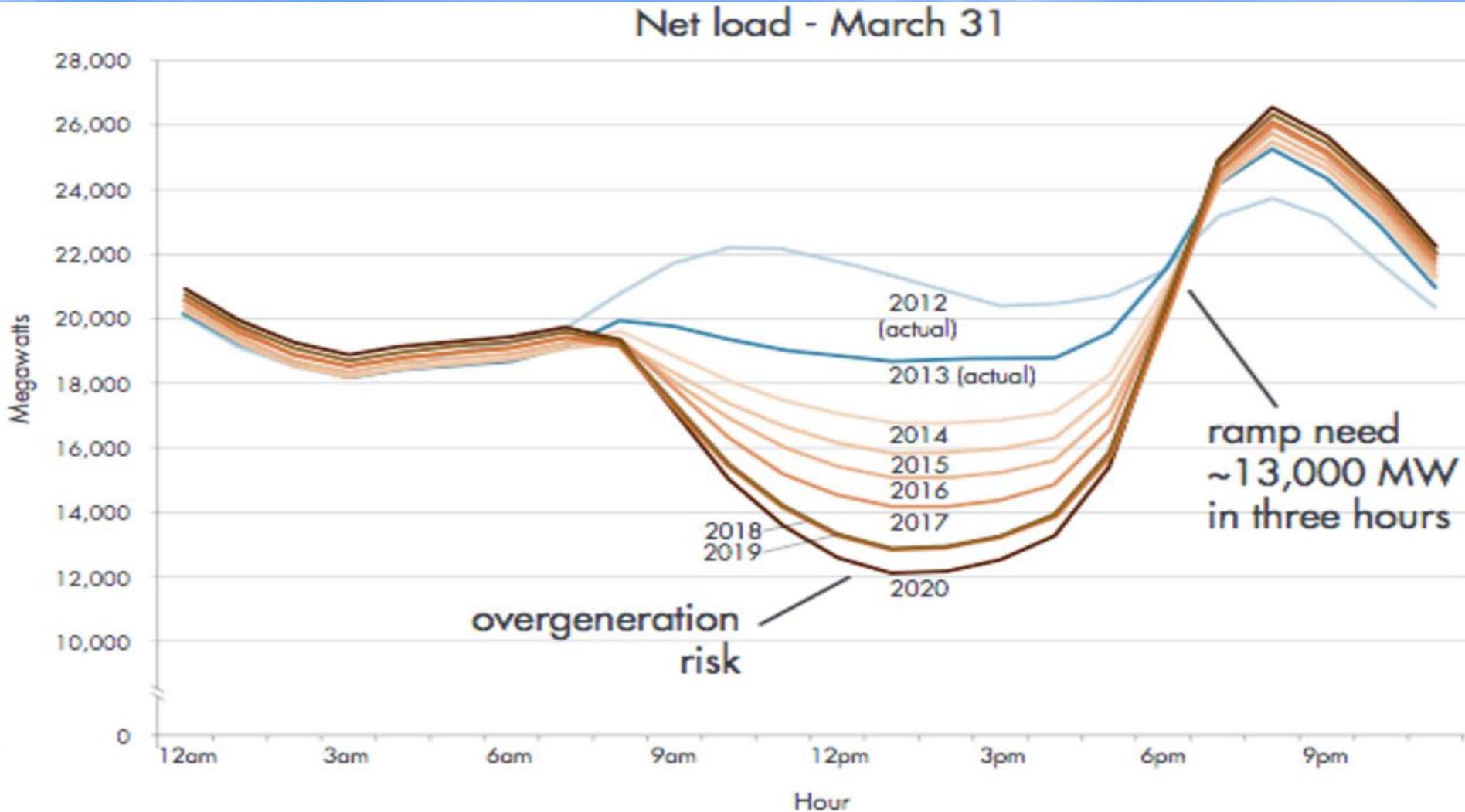
Sources: California Energy Commission

By Jiachuan Wu | REUTERS GRAPHICS

Inside Energy: Why Is California Trying To Behead The Duck?

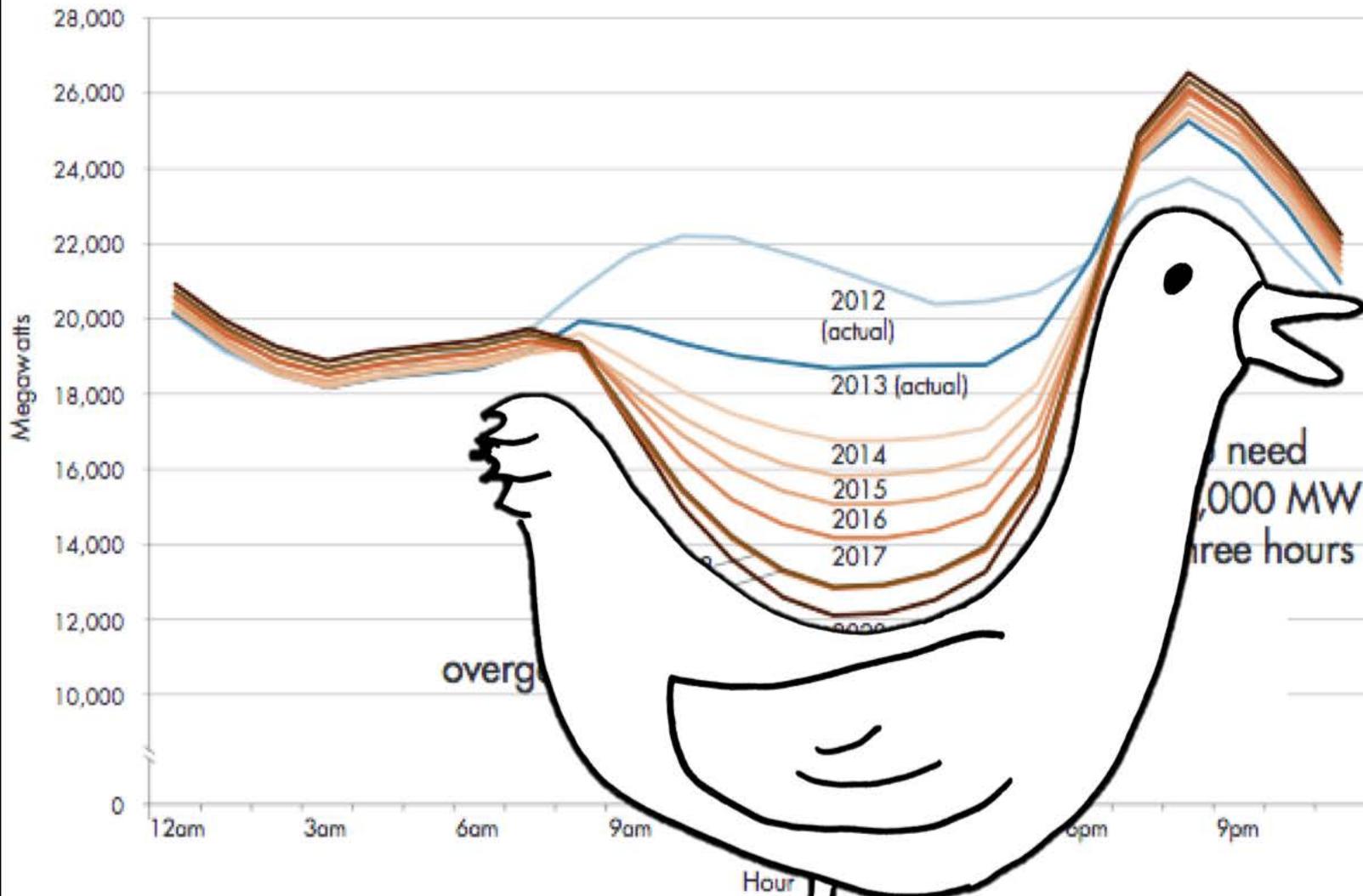
By Jordan Wirfs-Brock, October 2, 2014,

<http://insideenergy.org/2014/10/02/ie-questions-why-is-california-trying-to-behead-the-duck/>



Net load curves for March 31, from 2012 to 2020, based on analysis by California ISO. Source: California ISO.

Net load - March 31



Quack!

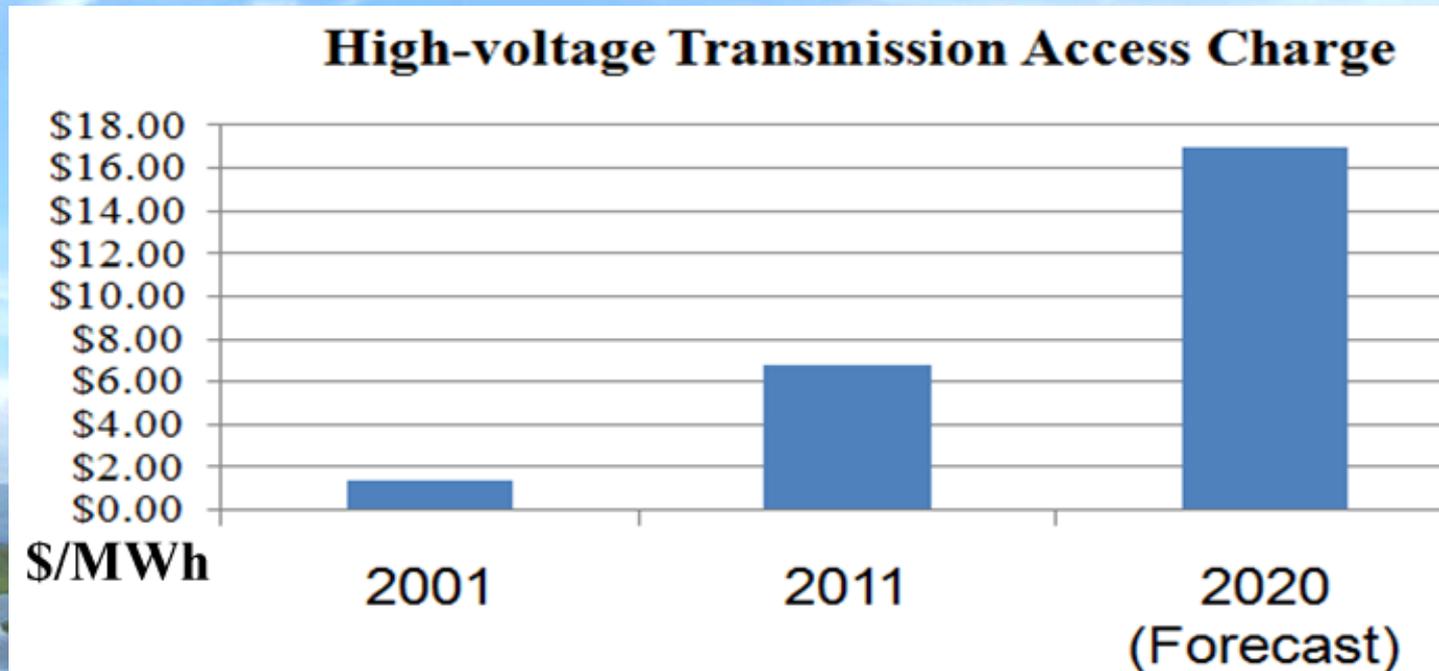
overg

need
0,000 MW
three hours

A New Alternative - Space Solar Power (SSP)

11. Not only lower cost *generation* but lower cost *access*.

A transmission grid based on the central generating station model is simpler, more reliable, and lower cost than rebuilding to a distributed generation model. To meet California's 33% RPS goal, ratepayer bills will rise drastically by 2020, not just from renewable energy's higher cost, but also from CA-ISO's required transmission upgrades:



The inflation-adjusted net worth for the typical household was \$87,992 in 2003. Ten years later, it was \$56,335, a 36 percent decline. The average electric power bill increased 42% between 2003 to 2013.

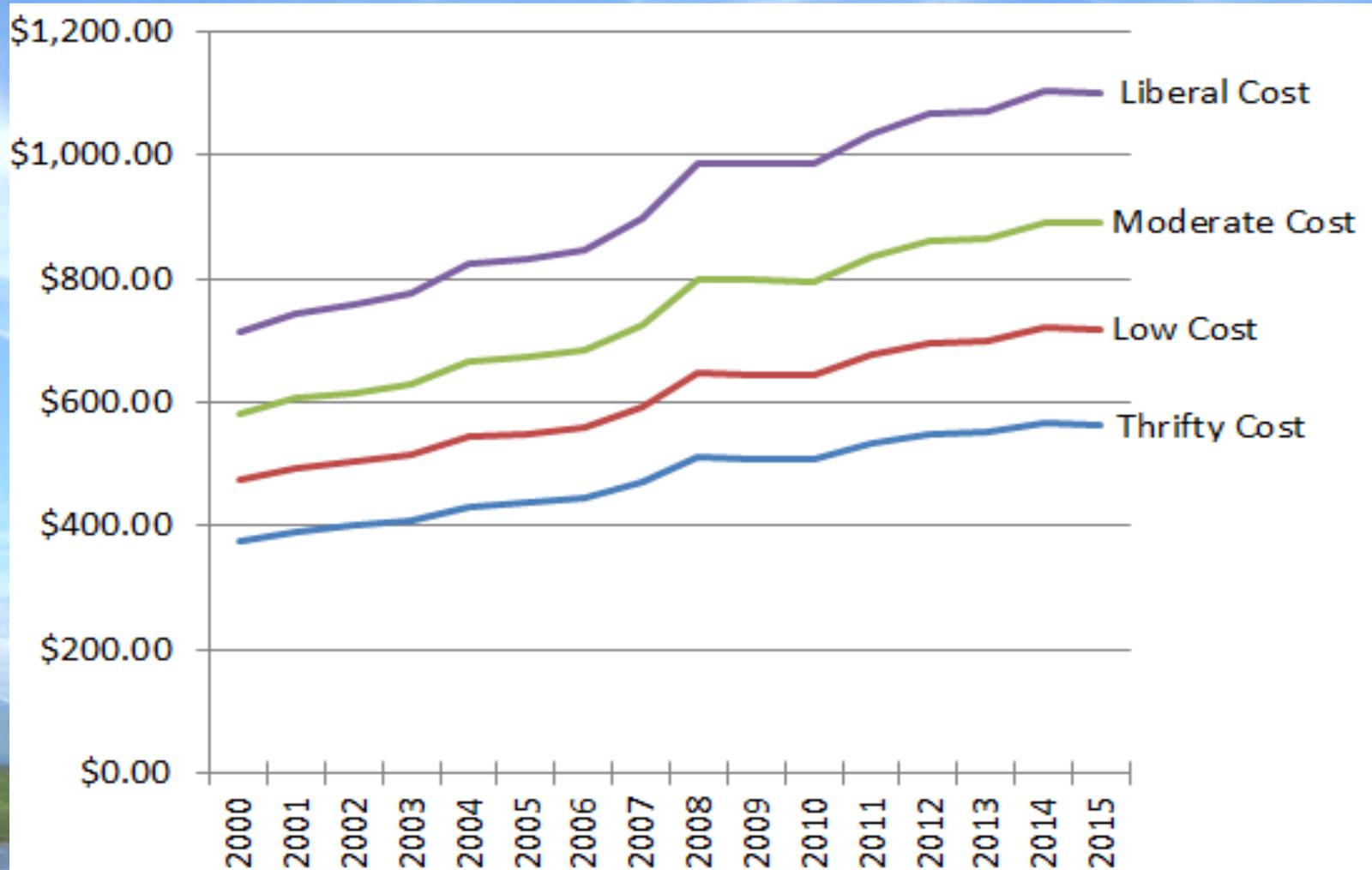
Table 1. Wealth of American households before and after the Great Recession (in 2013 dollars)

	2003	2007	2009	2013
Mean	337,233	423,592	411,178	308,276
Percentiles				
5 th	-9,749	-13,482	-27,689	-27,416
25 th	10,129	6,966	2,723	3,200
50th (median)	87,992	98,872	70,801	56,335
75 th	302,221	367,959	302,412	260,405
90 th	736,853	934,223	819,824	763,099
95 th	1,192,639	1,629,133	1,420,304	1,364,834

Source: Panel Study of Income Dynamics (based on 2013 early release data);

Food Costs

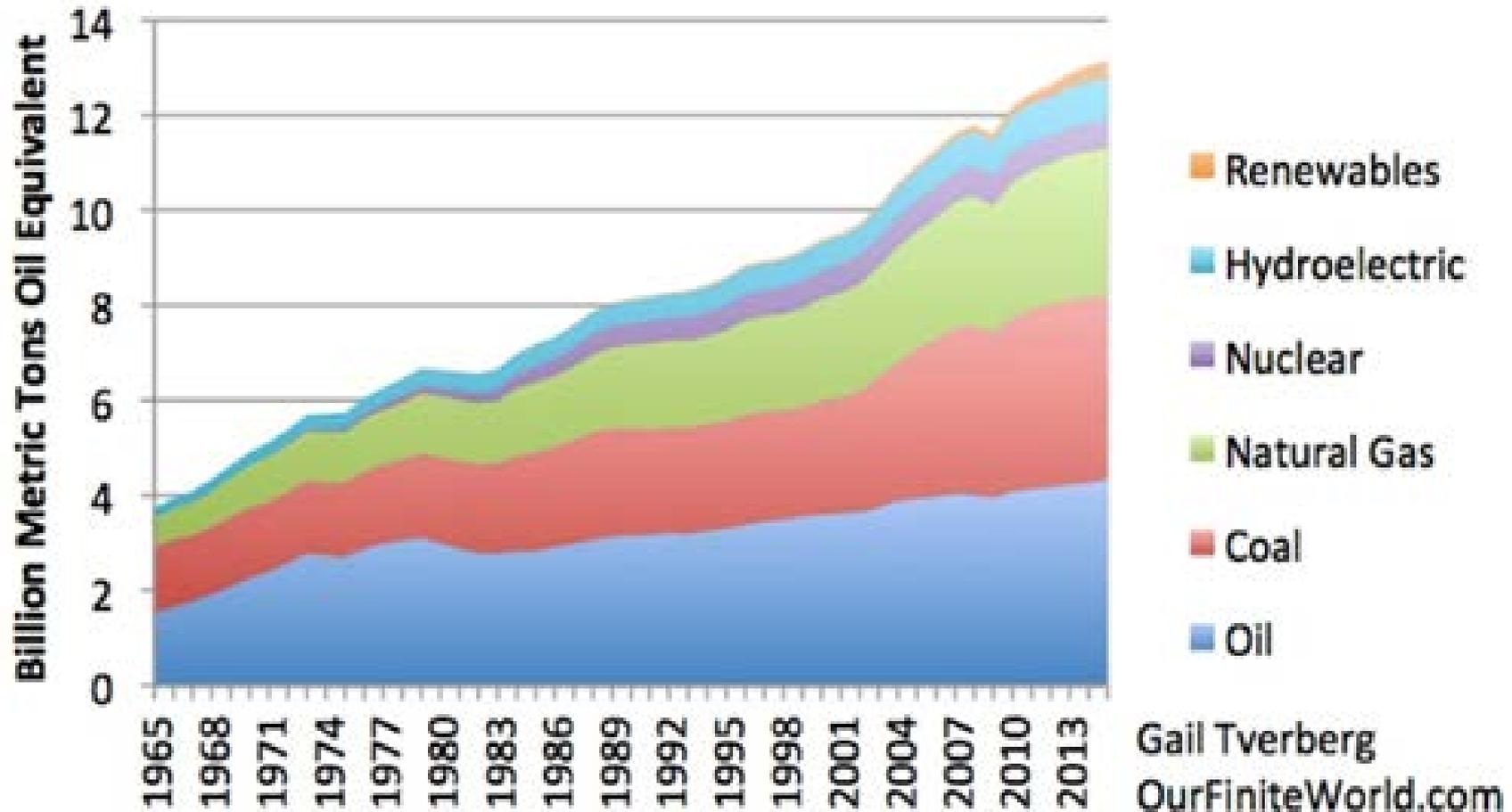
ALL four monthly food plans which the USDA tracks increased by more than 50% from 2000 through 2015. (family of four data plotted)



“Effective control of rising CO₂ is not financially feasible for even large electric power generation companies, using currently available technologies and RPS constraints. These companies and customers are *not* "capable of shouldering heavy substantive and procedural burdens. (EPA wording)" as their visceral connection to global economies prohibits deploying grossly non-economic and reliability-reducing power generation technologies. Space Solar Power is required to effectively address rising global CO₂.”

- Summary statement for Atlanta EPA Public Hearing
November 19, 2015

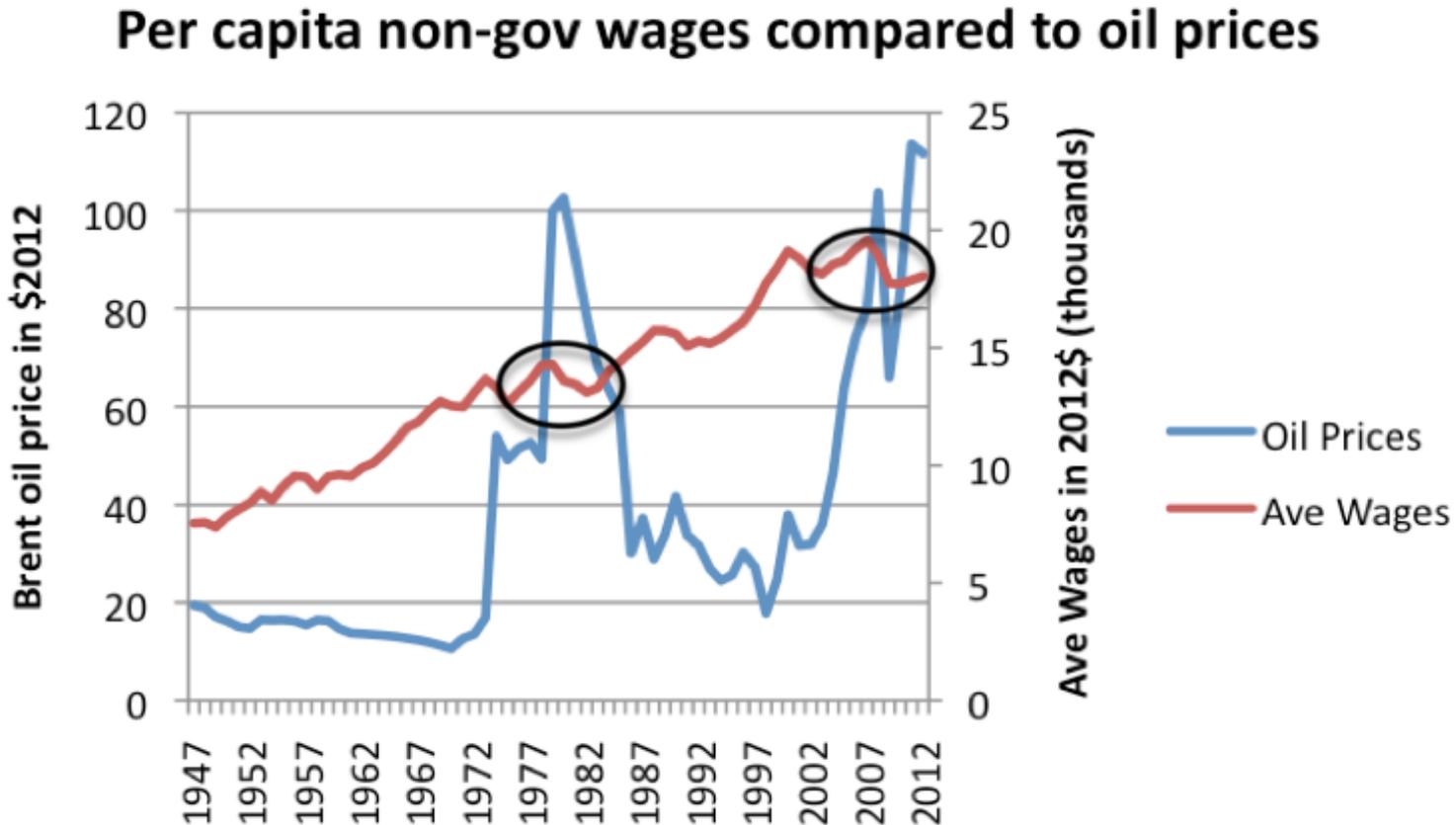
World Energy Consumption by Fuel



Data from BP World Energy 2016. Chart by Gail Tverberg, Director of Energy Economics, Space Solar Power Institute

High oil prices lead to RECESSION

Economist James Hamilton has shown that oil price spikes connected with 10 out of 11 recent US recessions! Our global and U.S. economy is dependent on stable and reasonable energy prices, especially oil, which directly affect commodities costs.



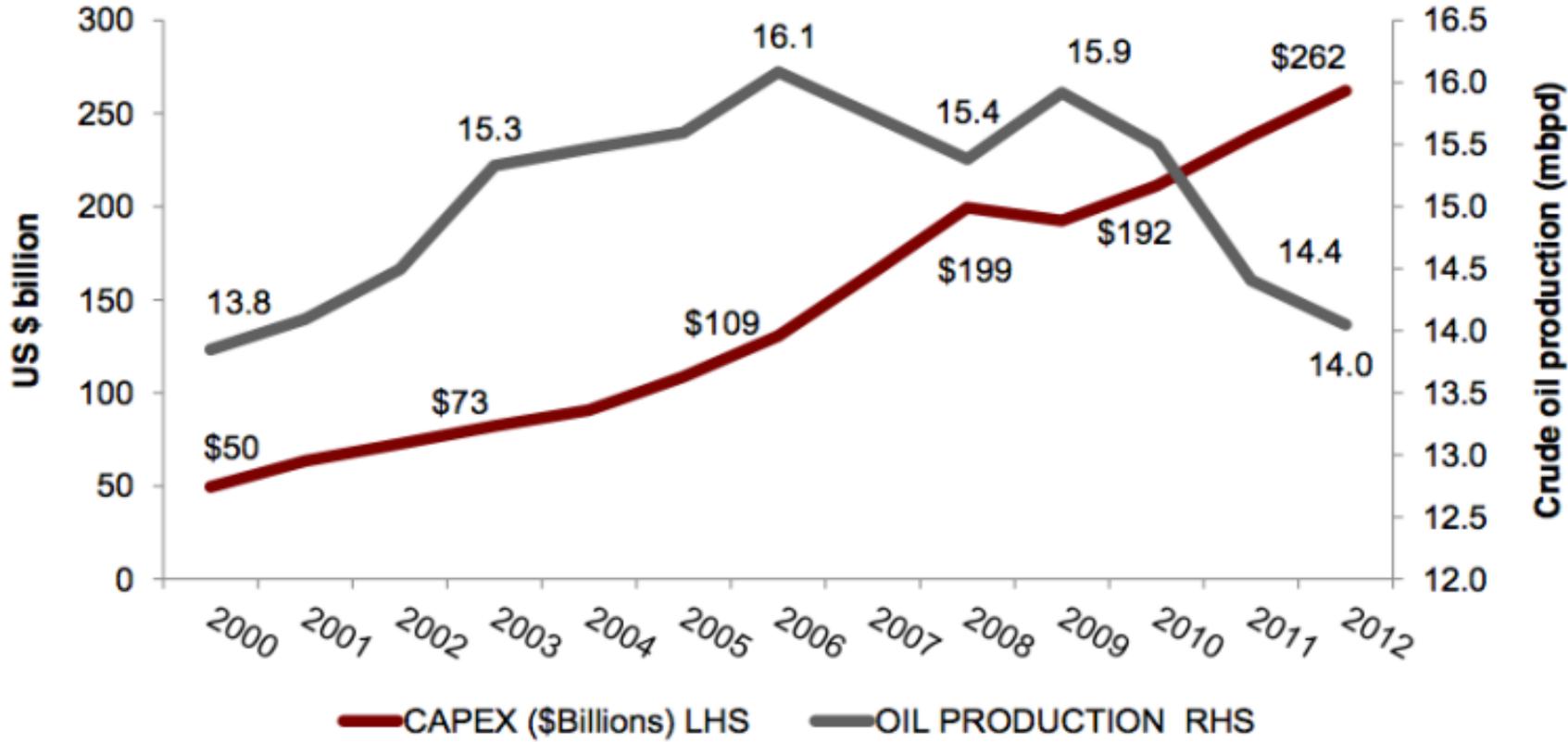
Monthly Average Brent Oil Price

Too high for consumers



Chart by Gail Tverberg, Director of Energy Economics, Space Solar Power Institute

Listed Oil Majors: Capex and Crude Oil Production



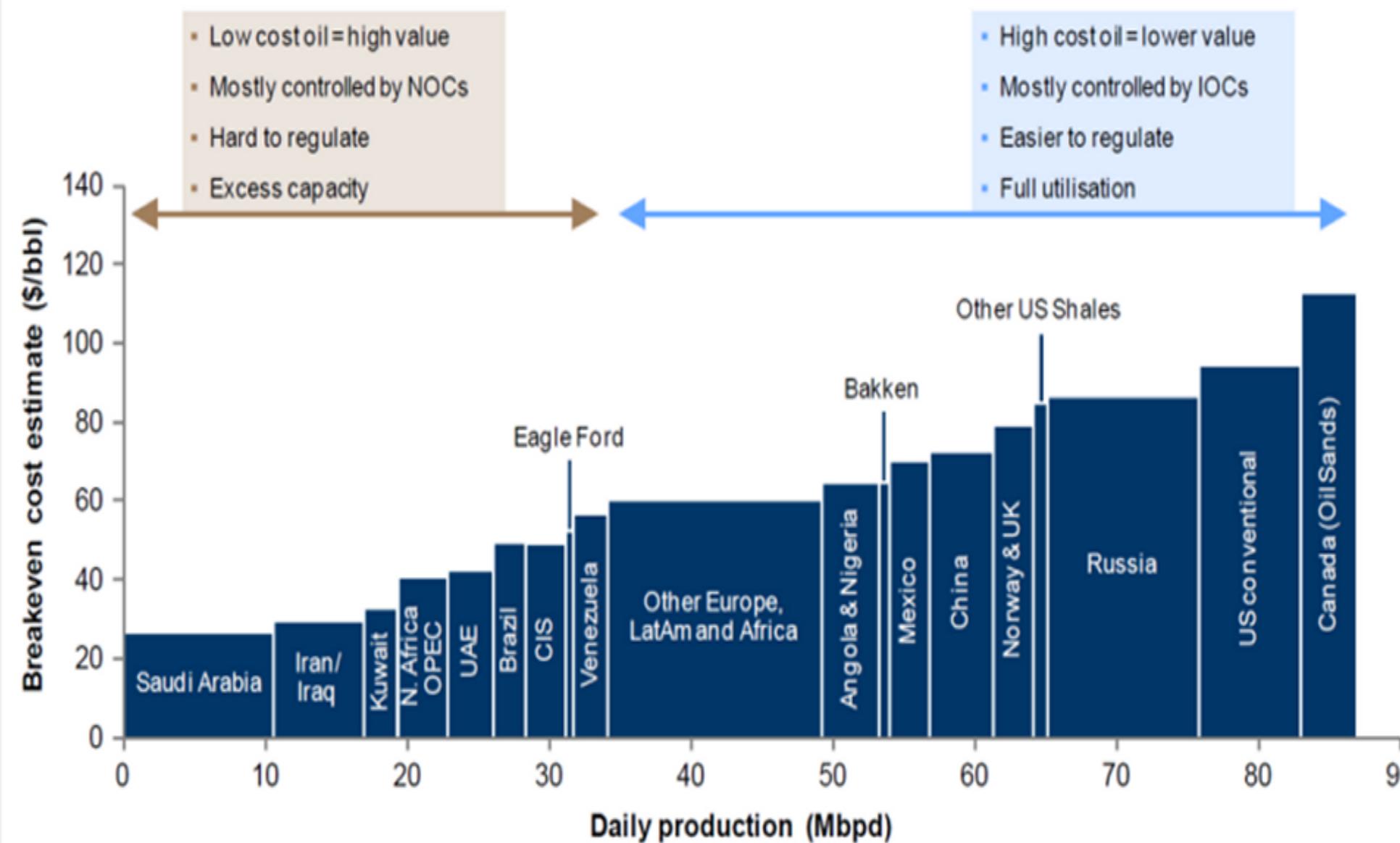
Crude Oil Production and Capex

Combined data for BG, BP, COP, CVX, ENI, OXY, PBR, RDS, STO, TOT, XOM

Source: Bloomberg via Phibro Trading LLC

- Oil production has faltered, even as capex has soared
- Capex productivity has fallen by a factor of five since 2000
- Observed decline trend now approaching 5% per year

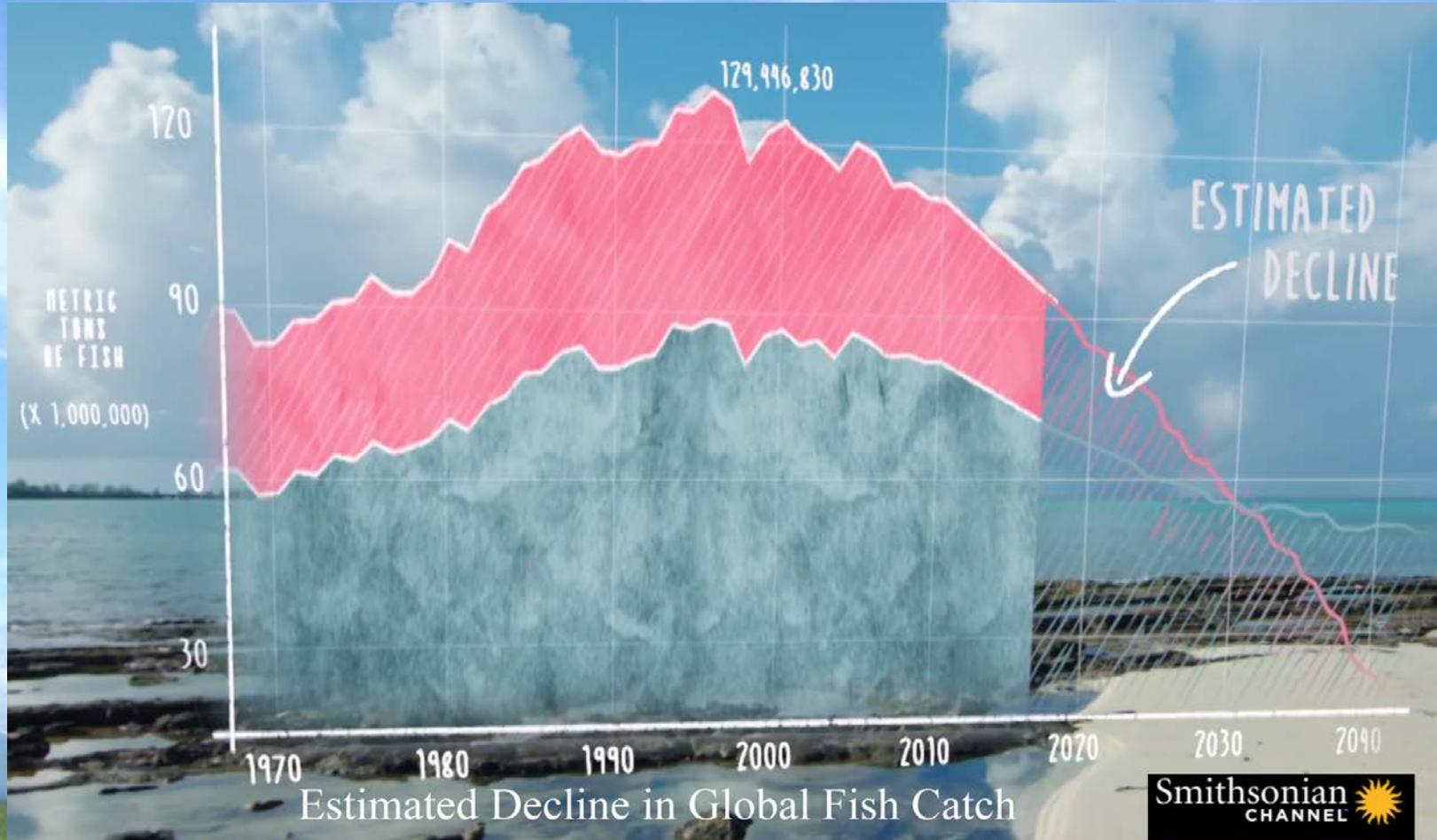
Global breakeven prices (considering only technical extraction costs) versus production



Source: Alliance Bernstein, Oct 2014; from "Why oil under \$30 per barrel is a major problem"
<https://OurFiniteWorld.com/2016/01/19/why-oil-under-30-per-barrel-is-a-major-problem/#more-40536>

Climate Change - nutritional

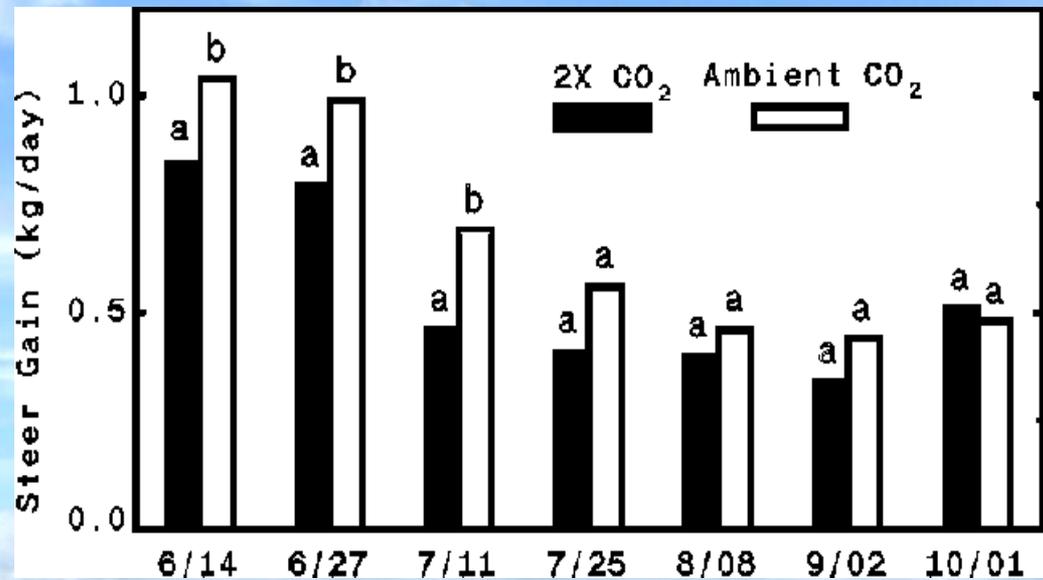
Laboratory duplication of the changes affecting the oceans in the years ahead is virtually impossible. Oxygen levels in the Pacific tropics has been declining since the 1970s. Measuring *today's* ocean productivity shows that since 1996 global catch has been in decline.



Climate Change - nutritional

Plant-available nitrogen decreases 40 to 50 % under doubled carbon dioxide levels expected around 2050 ... resulting in reduced nutrition from forage and grasses grown under doubled CO₂ .

Ruminants, including cattle, sheep, oxen, buffalo, deer, etc., the source of nearly all the milk and half the meat the world eats, will gain weight more slowly under doubled CO₂ >>>



Kansas State University <http://spuds.agron.ksu.edu/gainco2.gif>

Climate Change - nutritional (2)

- Nutrition from wheat and rice decline:
- Wheat grown at doubled CO₂ declines in protein content by 9-13%. It produces poorer dough of lower extensibility and decreased loaf volume. The quality of flour for bread making degrades.
- The protein content of rice declines under doubled CO₂ corresponding temperature increase. Iron and zinc concentrations in rice, important for human nutrition, would be lower.

Climate Change - Summary (3)

As our atmospheric CO₂ level continues to increase, plant photorespiration decreases and nitrate assimilation in most plant species is severely inhibited. Declines in forest health and food quality that are associated with climate change derive in part from CO₂ inhibition of nitrate assimilation that diminishes plant organic N (Nitrogen, and therefore, protein concentration.) levels. This exacerbates damage from insects and other pests as they consume more plant material to meet their nutritional needs.

- **“Elevated Carbon Dioxide”, Arnold J. Bloom, Ph. D, Professor and chair, Dept. of Plant Sciences, Univ. of California, Davis.**
www.plantsciences.ucdavis.edu/Faculty/bloom/bloom.htm

The current wave of Arab wars began with the “Arab Spring”, whose #1 cause was the rising price of food. ISIL’s war is basically over control of Iraqi oil fields.



Natural Gas Prices

20
Dollars per
Million BTU

Henry Hub Natural Gas Spot Price

15

10

5

0

1998

2000

2002

2004

2006

2008

2010

2012

2014

— Henry Hub Natural Gas Spot Price



Source: U.S. Energy Information Administration

Natural Gas Prices

Between 1999 and 2004, the US electric power industry built **200,000 MW** (about “4 Californias” worth of generation capacity or almost 10% of all US generation) of natural gas fired generation. Natural gas was cheap - \$2 to \$3 per Million BTU. By Dec 2005 the price soared above \$14 per Million BTU and US electric power consumers were burned. The DOE then retracted their estimation that Mexican natural gas would remain cheap.

Natural gas has now, once again, entered that “cheap” range.

No company(s), countries or agency(s), are yet prepared to assume the immense financial risk of initiating SSP construction.

There are simply too many engineering, financial, regulatory and managerial risks for any group we have been able to identify to undertake SSP today.

No Utilities can order a Sunsat yet.

Current Research and Development of Wireless Power Transfer via Radio Waves and the Application [DML]

Apr. 7, 2017

Naoki Shinohara, Professor,
Research Institute for Sustainable Humanosphere,
Kyoto University
shino@rish.kyoto-u.ac.jp

MPT Experiment on Feb. 2015

Thin-High Efficiency Phased Array with GaN MMIC

2.5cm thickness phased array
GaN MMIC Amplifiers
5.8GHz, 1.8kW



WPT Ground Test

Rectenna
Array
Receiving
Section

Microwave
Beam

55m

Power Density
 $\sim 350\text{W}/\text{m}^2$
at rectenna center
 $\sim 10\text{W}/\text{m}^2$
at rectenna edge

Microwave
Phased Array
Transmission
Section



The 5th Annual IEEE International Wireless for Space and Extreme Environments (WISEE 2017) Conference will be held October 10 to 12, 2017 at Concordia University, Montréal.

Workshop on Space Solar Power (SSP) @ WISEE 2017

Call for Papers and Presentations

Chairs: Seyed (Reza) Zekavat (Michigan Tech), Darel Preble (Space Solar Power Institute)

This two-day workshop will provide a forum for researchers and developers working on space solar power (SSP) topics to highlight progress and needs, to discuss these different technologies, and take necessary actions toward the implementation of solar power satellites or sunsats. Workshop information will be posted on the workshop's website.

The topics include but not limited to:

1. **Communication requirements and Interference studies for SSP construction, including ITU adoption of a frequency assignment for SSP use;**
2. An assessment of the most relevant technologies and implementations for SSP;
3. Opportunities for cooperation and competition to promote development of SSP technologies.
4. Communication requirements (frequency allocation for SSP use, interference & bandwidth) with sensors and robotics structures for SSP;
5. Wireless Power Transfer (WPT) / Microwave Power Transfer (MPT) Technologies including (space-to-space, space-to-ground, ground-to-ground, ground-to-space) grids;
6. Needs for Educating Next Generations while stimulating development of WPT/MPT;
7. SSP Photovoltaics power planning, superconducting power management design, construction, maintenance and operational techniques
8. SSP Energy-Economics overview; Fossil Energy Resources and Green Energy alternatives;
9. National & International SSP projects (technologies, industries, companies, coordinated Research, SSP Power Beaming Competitions and challenges);
10. Wireless Channel (impact of power; frequency, bandwidth);
11. Massive Phased Arrays/MIMO and Beam-forming strategies for WPT/MPT;
12. Antenna and Solar Cell integration Technologies;
13. Power Harvesting (e.g., Rectenna) Design;

Please see WISEE 2017 **Call for Papers** at <http://sites.ieee.org/wisee/call-for-papers>

Paper/poster submission Deadline:

July 1, 2017

Acceptance notification:

August 1, 2017

Early registration deadline:

August 15, 2017

Final camera ready paper:

Sept. 1, 2017

Challenges to closing the SSP Business case - 1

Financial - Low Cost to Orbit - Reusable Transportation(RLV)

FAA's Annual Compendium reviews essentially all global launch vehicles on the immediate horizon, but its getting harder to keep up -



Federal Aviation Administration

The Annual Compendium of Commercial Space Transportation: 2017

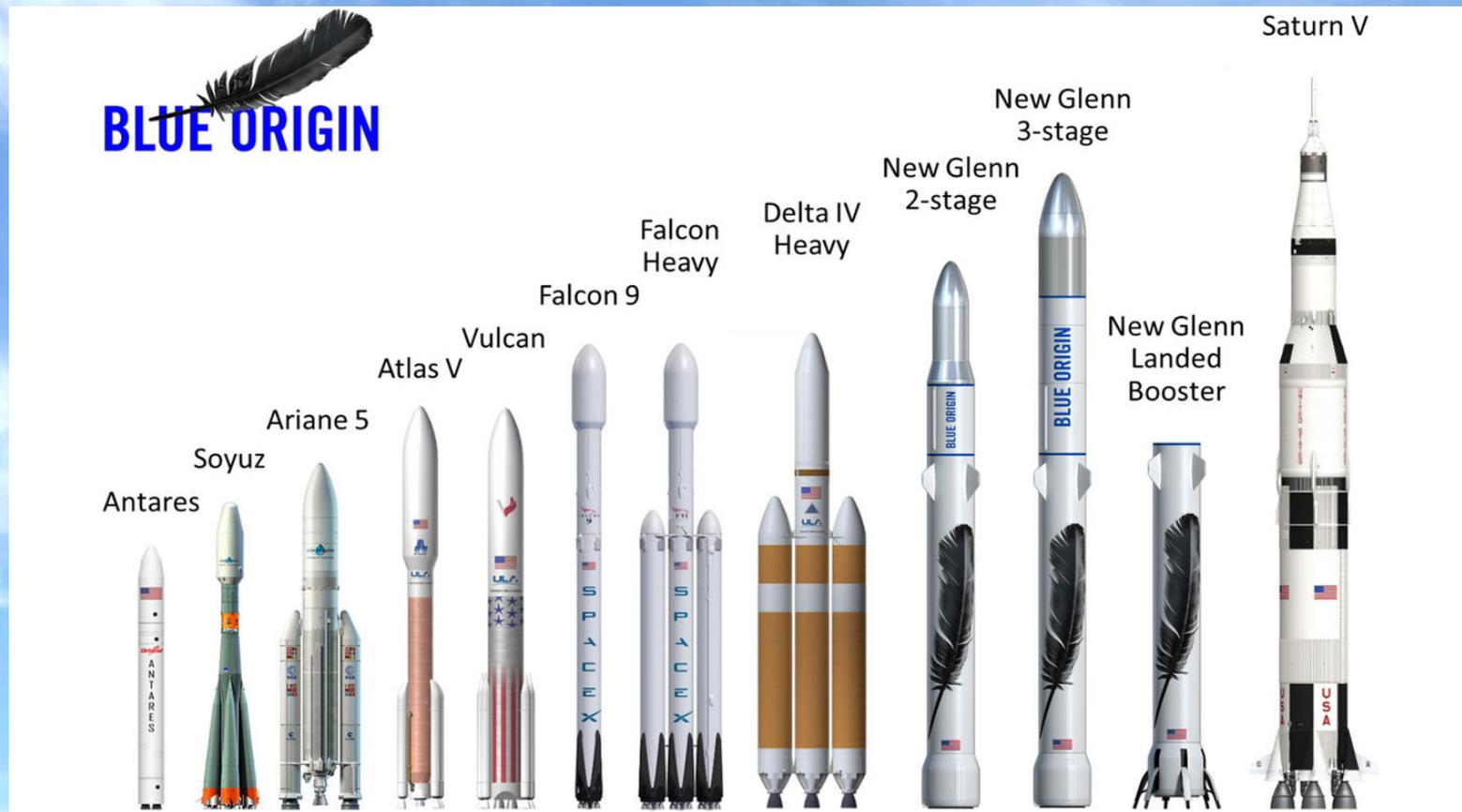


DARPA selects Boeing for XS-1 RLV spaceplane

May 24, 2017 -WASHINGTON — DARPA picked Boeing to develop their experimental reusable first stage, promising to lower launch costs for medium-sized payloads. Boeing will develop its “Phantom Express” vehicle for phases 2 and 3 of DARPA’s Experimental Spaceplane 1 (XS-1) program, which has the goal of performing 10 flights in 10 days, with one flight over Mach 10, to demonstrate responsive and low-cost launch. Phase 2 will cover development of the vehicle and ground tests through 2019, with a series of 12 to 15 test flights planned for phase 3 in 2020.



Top 10 Challenges to closing the SSP Business case - 1



Named for astronaut John Glenn, the New Glenn rocket's diameter will lift off with 3.85 million pounds of thrust from seven engines. That places it between SpaceX's Falcon 9, and the Falcon Heavy, with more than 5 million pounds of thrust at liftoff.

- Los Angeles Times, Sept. 12, 2016

Stratolauncher

Paul Allen, Microsoft billionaire, is financing [Stratolaunch Systems](#) now located in Huntsville, AL and focused on building the world's largest aircraft, using six Boeing 747 engines, to “air-launch” payloads to orbit. Stratolaunch has [selected Orbital's Pegasus XL](#) to launch to orbit:



Stratolaunch Systems' aircraft carrying three Orbital ATK Pegasus launch vehicles. Credit: Stratolaunch Systems

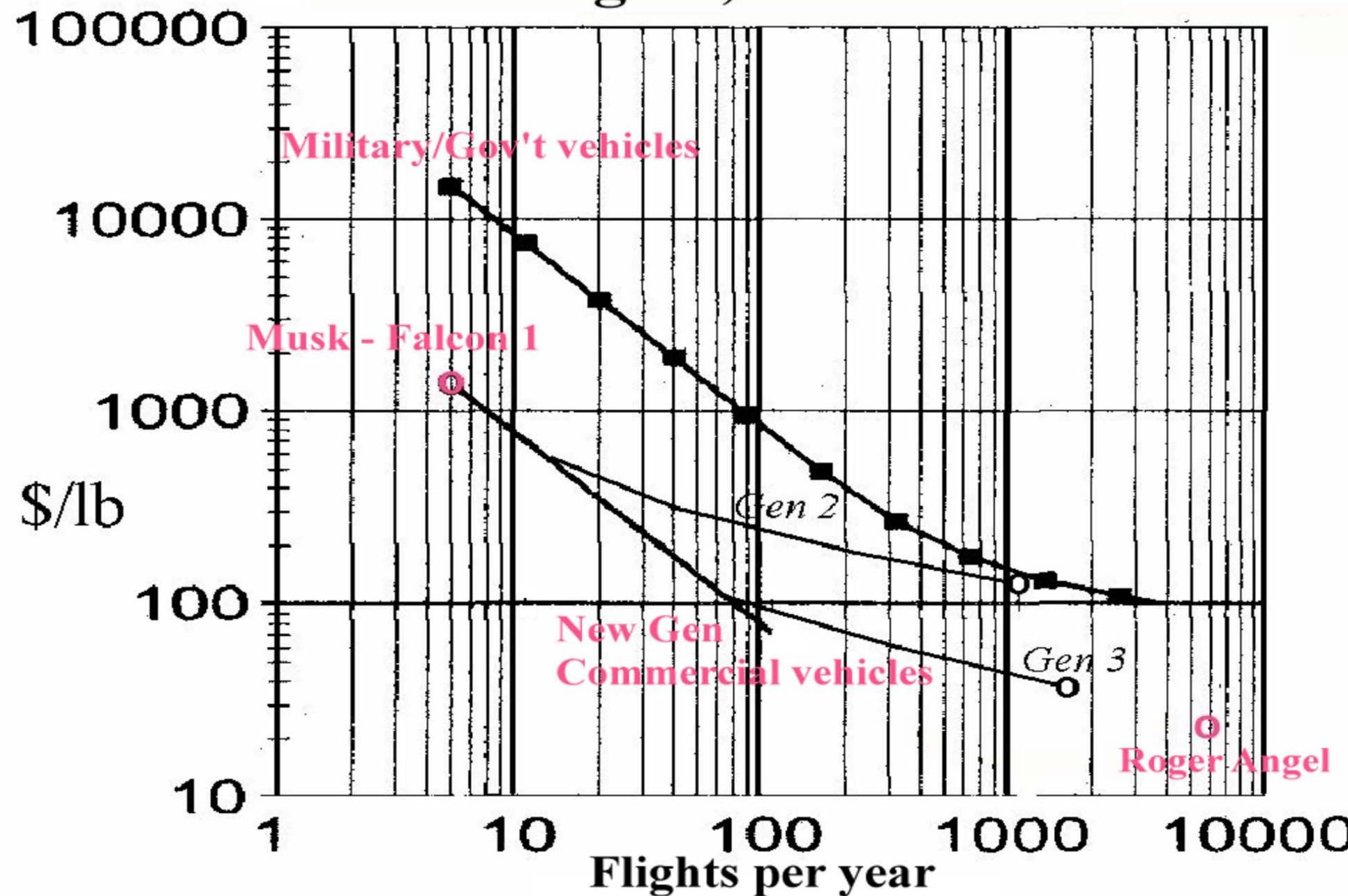
Electromagnetic Aircraft Launch System (EMALS)

Eventually SunSats could receive an electromagnetic launch boost from the Navy's EMALS now being installed in CVN-21 Carriers.



<http://defensetech.org/2015/03/19/navy-prepares-to-fire-an-electromagnetic-aircraft-catapult-on-new-carrier/>

More Flights, Lower Cost



Military/Gov't curve by Gordon Woodcock

Rockets for Space Solar Power (SSP)

"The payload penalty for full and fast reusability versus an expendable version is roughly 40 percent," Musk says. "[But] propellant cost is less than 0.4 percent of the total flight cost. Taking into account the payload reduction for reusability, the improvement is therefore theoretically **over a hundred times.**" This would drop the cost per kg for his Falcon Heavy rocket to just \$10. That, however, requires a very high flight rate, just like aircraft," Musk says. - **“Elon Musk on SpaceX’s Reusable Rocket”, Feb. 7, 2012,**

<http://www.popularmechanics.com/science/space/rockets/elon-musk-on-spacex-reusable-rocket-plans-6653023>

A New Alternative - Space Solar Power (SSP)

Space Solar Power is estimated to have an EROI of 300 or higher, using thin-film photovoltaics and reusable commercial launch vehicles(RLV). Achieving that EROI depends on getting RLV's above 100 times reuse, cutting launch to orbit prices down to about \$150 per lb. to orbit. Elon Musk's SpaceX, is leading this race:

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<http://www.popularmechanics.com/science/space/rockets/elon-musk-on-spacexs-reusable-rocket-plans-6653023>

Space Solar Power Initiative Established by Northrop Grumman and Caltech

PASADENA, Calif., April 20, 2015 /PRNewswire/ -- Northrop Grumman Corporation has signed a sponsored research agreement with the California Institute of Technology (Caltech) for the development of the Space Solar Power Initiative (SSPI). Northrop Grumman will provide the initiative \$17.5 million over three years. The team will develop the scientific and technological innovations necessary to enable a space-based solar power system capable of generating electric power at cost parity with grid-connected fossil fuel power plants. SSPI responds to the engineering challenge of providing a cost-competitive source of sustainable energy. SSPI will develop technologies in three areas: high-efficiency ultralight photovoltaics; ultralight deployable space structures; and phased array and power transmission.

How to proceed?

Comsat Corp, a public/private corporation chartered in 1962, opened space for communication satellites - when we knew *nothing* about space, rockets or space communications. Communication satellites are now a \$300+/-year Billion industry. The “Sunsat Act” would accomplish the same task, creating a space solar power corporation and industry of far greater size.

The first US aerospace company, **Northrup Grumman** has now thrown their hat in the SSP ring, **signaling that the checkered flag has just dropped** for the US Sunsat competition!!

