The Energy Economics Motivating Space Solar Power Development

Gail Tverberg, FCAS, MAAA, MS – March 19, 2013
Outline

- My background
- Energy use underlies our economy
- We are reaching limits because of our energy usage
  - Particularly oil
- Our current situation may end badly
- Fuel requirements to fix our energy predicament
- How global space solar fits in
Energy use underlies our economy
Energy makes the world go around

Source: Jewishworldreview.com
Energy allows us to transform raw materials into finished products

- Extracting raw materials requires energy
- Transport requires energy
- Services require energy
Increased energy use is associated with increasing prosperity

Source: Based on 2012 BP Statistical Review of World Energy and USDA Economic Research Data
Energy use escalated when China joined World Trade Organization in Dec. 2001!

Source: Based on 2012 BP Statistical Review of World Energy.
Oil consumption declining in bank bailout countries

Source: Based on EIA International Energy Statistics.
Population grows as fuel use grows

- Fuels allow more food, better medicine and sanitation
- Human population growth started with control of fire!

![World Population and Fuel Use Growth]

Population in less developed countries is still growing rapidly

- **All species** reproduce more than needed for replacement
- Fossil fuel permits cutting both birth and death rate

Source: Based on EIA International Energy Statistics.
Examples of usable energy sources

- Human
  - $$$$$$$$$$$$
- Animal
  - $$$$$$$$
- Oil
  - $$$$$$
- Electricity
  - $$$
- Coal
  - $

Sources differ in nature: electricity is an energy carrier; humans and animals use food to generate the energy they provide.
Cost of replacing built infrastructure is a huge problem

Worldwide machinery operating on oil is valued at $50 to $100 trillion (Automobiles, airplanes, tractors, trucks, ships, buses, etc.) – Robert Hirsch – ASPO 2012

Source: Transportation Blog, DallasNews.com
We are reaching limits because of our energy usage
Cost Limit

Source: Fossil fuel cost from EIA Table Annual Energy Review Tables 3.2 and 3.9, wages from BEA Table 2.1.
High cost leads to lower energy consumption – Not affordable!

Source: Wages from BEA Table 2.1. Fossil Fuel costs from EIA Annual Energy Review Tables 3.2 and 2.9. Total energy consumption (includes renewables) from EIA Annual Energy Review Table 1.3; Population from EIA Int. Energy Statistics.
Population Limits

- Too many humans squeeze other species
- Now 7 billion humans; fewer than 200,000 chimpanzees
- Biomass use near limits* - can’t keep increasing biofuels

Pollution limits: Air, water and CO2

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

Energy

Figure 1. U.S. primary energy consumption by fuel, 1990-2040 (quadrillion Btu/year)
Source: EIA AEO 2013 Reference case
84% fossil fuel in 2011; 80% in 2040.
Fresh water limits

- Coal-fired electric, base-load gas, nuclear-electric plants
- Biofuels

Source: BikingIllinois.com
Soil quality increasingly degraded—Depends on fossil fuels to temporarily fix

Source: www.public.iastate.edu
Entropy – 2\textsuperscript{nd} Law of Thermodynamics

- Everything degrades
- Need increasing amounts of energy to fix roads, pipelines, bridges, houses
Quality of resources is declining

- Extract the best, cheapest first
- Move on to the more expensive
- Always seems to be more!
- True for fossil fuels, metals, water
- Reason reserves increase
  - Low quality!
- Reason cost of extraction is up
Oil in particular is reaching limits
Oil quality is declining

- Light oil – flows like milk
- Heavy oil – like peanut butter
- Tight oil (using “fracking”)
  - Like from pores of concrete driveway
- Takes much longer to extract
- Costs much more
- Reason today’s prices are high!
- Becomes “Investment Sinkhole”
US oil production shows how depletion can work

- Unexpectedly started declining in 1970

Source: Based on EIA Data
World oil production is now close to flat

- One concern: It too will nose dive
- US and Canada account for all recent growth

Source: Based on US Energy Information Administration data. *2012 based on partial year.
Another concern: Historic big users losing out

- Too many at the table
- Growth goes to countries that obtain oil

![Oil Consumption by Area](source: Based on 2012 BP Statistical Review of World Energy data)
Another concern: High oil prices lead to RECESSION

- Economist James Hamilton has shown that oil price spikes connected with 10 out of 11 recent US recessions!

Source: Based on BP 2012 Statistical Review of World Energy data
Food and oil prices tend to rise together

- Oil used in plowing, harvesting, transport, herbicides, pesticides, irrigation

Source: Oil is spot oil price from EIA; food index is from Food and Agriculture Organization of the United Nations.
Another concern: High oil prices lead to depressed wages

- As expected, if switch is away from *human wages*

Source: 2012 BP Statistical Review of World Energy, BEA Private Industry Wages, and CPI-Urban from BLS.
How high oil prices lead to depressed wages

- Businesses seek to mitigate falling profits

Source: Illustration by author.
Our current situation may end badly

Source: Chart from PaulChefurka.ca
Resource overuse and collapse is very frequent

- Joseph Tainter - *The Collapse of Complex Societies*
  - Focus - increasing resource requirements with growth

- Sing Chew - *The Recurring Dark Ages*
  - Focus - ecology, deforestation, climate change

- David Montgomery - *Dirt: The Erosion of Civilizations*
  - Focus - soil degradation

- Peter Turchin and Sergey Nefedov – *Secular Cycles*
  - Focus - how collapses manifest themselves, timing
  - About 300 year cycle; major financial impacts
  - Growth, Stagflation, Crisis, Intercycle
  - My view: Current cycle may have begun about 1800, with coal
How current limits may manifest themselves – My view, based on Turchin model
Expected Kinds of Issues

- **Financial**
  - Too much debt; defaults
  - Rising price of food and fuel
  - Huge wealth disparities

- **Political**
  - Can’t collect enough taxes
  - Citizen revolts
  - Possible collapse; government overthrow

- **Disease Susceptibility**
  - Too many poor; unemployed
  - Government forced to cut back on services
Government caught in the middle

Wage Earners

Industry

Subsidies

Credits: Texaspolicy.com, Thetaxhaven.com.au, Usahitman.com, politic365.com, autoevolution.com
Governments already having trouble collecting enough taxes

- Relates to lower wages, globalization lowering business taxes

Source: Based on US Bureau of Economic Analysis data.
Fuel requirements to fix our energy predicament
Current approach is not working

- Coal biggest increase; new renewables total 2%

Source: Based on 2012 BP Review of World Energy.
World carbon dioxide emissions are increasing at record rate

Source: Based on 2012 BP Statistical Review of World Energy data. Trend line fitted by author.
Need to get energy costs down from today’s current high level

Source: Fossil fuel cost from EIA Table Annual Energy Review Tables 3.2 and 3.9, wages from BEA Table 2.1.
Characteristics of Needed Replacement Fuels

- Inexpensive
  - Cheaper than today’s fuels
  - Expensive fuels don’t “scale”
- Uses resources sparingly
- Not polluting (CO$_2$ and other)
- Doesn’t add hidden costs
  - Intermittency
  - New infrastructure
- Available in very large quantities
- Self financing, or financed primarily by industry
- Available now
How global space solar fits in
A New Alternative – Space Solar Power

Simple, in principle
... Integrated Symmetric Concentrator design shown

Financially, SSP is like building large solar “Hoover dams” in high orbit.
Project already underway in Japan

Mitsubishi, IHI Join $21 Bln Space Solar Project

Japan’s USEF consortium is developing a 1-gigawatt solar station by 2030. It would produce electricity at eight yen (nine cents) per kilowatt-hour, one sixth the cost of solar electricity in Japan.

Sources: bloomberg.com/apps/news?pid=newsarchive&sid=aF3Xi.TvisJk,
Stations may be built by robots

ASTRO Captures NextSat

On July 23, 2007, for the first time ever, a satellite autonomously rendezvoused with and captured another orbiting satellite, pioneering future robotic work in space. ASTRO (Autonomous Space Transport Robotic Operations), part of Boeing’s Orbital Express system, successfully demonstrated advanced on-orbit satellite refueling and reconfiguration capabilities with NextSat. ASTRO, the robotic, on-orbit spacecraft mechanic, successfully captured NextSat. Orbital Express is a DARPA program which has validated on-orbit satellite servicing technologies.

Source: www.boeing.com/ids/advanced_systems/orbital/oe_057.html
Goal: Uses resources sparingly

- Generation uses no water
  - Big advantage over coal, nuclear, and biofuels
- Uses high purity silicone very sparingly
  - Doesn’t need to withstand earth weather, so PV only 1% as thick as conventional PV can be used
  - Capacity factor is 99.3% vs 18% on ground in US
  - 50% of electricity from PV output would get onto the power grid on earth
- Combined effect: silicone goes 275 times as far
- Other factors
  - Longevity of panels
  - Efficiency
Goal: Uses Resources Sparingly (cont)
Land use will be minimal

- Japanese plan uses dam reservoirs or areas at sea.

SSP uses almost no land since farming could be done under the elevated mesh rectenna.

Credit: MAFIC Studios
Resources used in flights to space still unknown

Prices drop as flight rate increases
Red dots are Elon Musk, SpaceX, $1300/lb and Roger Angel’s $20/lb (Sandia electromagnetic launch)

More Flights, Lower Cost

Cheap Rides? Falcon9, Dnepr, Kistler, ISRO Avatar,..?
Goal: Not Polluting

- Extraction of minerals of any kind is to some extent polluting
  - Requires fossil fuels, usually oil
- Burning of rocket fuel is also polluting
- One reason for need to keep costs low is so that the amount of this pollution remains low
  - Cost low-> Resource use low-> Pollution Low
- Eventually, SSP might be able to make its own fuel
  - Would need to combine carbon dioxide and water with electricity
- No $CO_2$ pollution from ongoing operations
Goal: Not Polluting (continued)

- Microwaves from space not expected to be hazard
  - Very diffuse, like cell phone microwaves
  - SSP ground component is a rectenna with benign power levels, within regulatory limits

Predicted ground-level microwave power density for a full-power GEO SPS as a function of distance –
Goal: Inexpensive

- Goal of Japanese group is 9 cents per kWh
- Ideally, need lower cost than this
  - Economy runs best on cheap energy
  - Low cost related to pollution, scalability, fixing economic woes
  - We badly need liquid fuels, and these need to be cheap too
    - Electricity needs to be very cheap to keep liquid costs low
  - Goal should be $20 to $30 barrel oil substitute
- If truly low cost, other countries would copy
  - Technology would spread, and other countries would benefit
Goal: Doesn’t add hidden costs

- Total cost is what is important
- SST is not intermittent
  - In fact, it is “dispatchable”
- Intermittency
  - Adds need for mitigation
    - Upgrades to grid regulation
    - Longer distance grid transmission
  - Cost of storage of electricity; loss of electricity on storage
  - Increases cost per kWh of fossil fuel electricity
    - Raises the cost of back-up electricity (lower utilization, more ramp-up/down)
    - Germany is finding that natural gas power needs subsidies, if wind gets subsidies
    - US has temporary situation with low cost gas; if gas price rises, it may face German problem
Goal: Doesn’t add hidden costs (cont.)

- Need for new infrastructure
  - Really need identical replacement of fuel to eliminate problem
    - In theory, with enough cheap electricity, SSP could create substitute
    - Time would still be an issue
  - Electric cars
    - Cost, range are problems
  - Huge amount of construction, farming, long haul truck equipment on oil
    - No electric substitute available
Goal: Available in very large quantities

- If SSP uses resources sparingly, much greater chance of ramp-up
- Even possibility of making liquid fuel, using electricity
  - Example: Ammonia available using water, air and electricity
  - We have been making liquid ammonia for 50 years for farming and moving it in pipelines. ([http://www.nh3fuelassociation.org](http://www.nh3fuelassociation.org))
  - Example 2: Isobutanol – Use water, air, carbon source, and electricity
  - Ideally, figure out how to combine CO$_2$ + H$_2$O -> Fuel
Goal: Self-Financing, or Financed Primarily by Industry

- Japanese example shows that industry-based approach can work
- A public/private Congressionally chartered corporation has all the requisite advantages. Comsat Corp., chartered in 1962, opened space for communication satellites.
- Communication satellites are now a $250+ Billion industry per year.
- The “Sunsat Act” would accomplish the same task, creating a space solar power corporation and industry of much greater size.
Available now

- Unfortunately, no.
- But neither is any other alternative that might meet these goals.
- We need to start work now, if Global Space Solar Power is ever to be available.
- Businesses will likely need to take lead on this.
  - Will need enabling legislation similar to 1962 Comsat Act.
  - Support from government.
    - My view: Don’t expect very much.
    - SSP Institute view: More optimistic – Needs not very high right now.
      - Japan’s budget only about $22 billion.
Space Solar Power Institute view

- We are working to get SSP initiated soon. The longer we wait to initiate SSP the more painful rising oil & gas prices (relative to wages, CPI, etc.,) will become before SSP can significantly ameliorate our massive global energy, economic and related environmental problems, since it will take decades to design, build and provide the terawatts of energy generation necessary to make a difference - _after_ we start.

- The funds needed to kick-start SSP are relatively small - for example, Japan's project budget is about 2 Trillion yen. (~$22 Billion)
Contact information

- Gail Tverberg
- Director of Energy Economics, Space Solar Power Institute
- www.solarsat.org
- OurFiniteWorld.com
- GailTverberg@comcast.net
- (407) 443-0505 (cell)