Energy From Space (ES)*: What Humanity Needs To Do and Why

- **WHY 1**: Future progress at all levels of society and development requires a revolution in the means of production. Eliminating scarcity caused by dependence on fossil energy is the best single **measure of progress J** in the larger world strategic picture. Views from me, Xi Jinping, Obama. Scientific approach: from J to action.
- **WHY 2:** Why energy from Space (ES), solar farms using solar power and land-based wind farms are the three best hopes to eliminate that dependence at minimum cost.
- **HOW**: Balanced new international R&D, and immediate new effort to design and prepare a new rocketplane to achieve $400/kg-orbit.

*Personal views of Dr. Paul J. Werbos only, not official views of NSF or US government

My View: We Should Think Ahead to the Best Possible Future

- Can >90% of humans on earth experience
  - Economic level ≥ normal US level
  - Personal feeling of freedom and growth ≥ best normal level in US history
  - With security – stability and sustainability?
- Can we also achieve sustainable growth for humans living in space?
- All policy should focus on two key issues:
  - Maximize the probability that we achieve this
  - Minimize the time delay before we do

The Good News

- **EARTH:** It is certain that we have the physical resources to achieve this goal, for all the present population of earth. Energy is the main constraint, because with energy we can manage water and sustain food production. Solar farms in deserts could supply about 100 times the electricity we use today – enough to accommodate big income growth in developing nations, electric transportation and more. But how, and how to minimize cost?
- **SPACE:** It is quite possible that we could achieve "economic takeoff" in space too. See the journal Futures, October 2009; see my paper in that special issue: www.werbos.com/E/Rational_Space_Policy.pdf. ES is our best hope for the needed exports from space to earth.

The Bad News: Three Main Threats or Obstacles to Overcome

- **Population growth**: If earth population keeps growing, we will lose the ability sooner or later to attain such a level. This problem has not been solved.
- **Conflict:** Humanity could act like a rich drunk, who has a beautiful house, but fills it with oil and burns it down. We could lose our potential through conflict – "Nash equilibrium inferior to Pareto."
- **Failure to develop and deploy affordable sustainable technology** before it is too late – due to problems with old vested interests like slave owners and oil companies. A global revolution in the means of production – eliminating energy scarcity and vested interests in human oppression – is an urgent need.

Scientific policy would focus on maximizing the probability of global success on all three. Today I focus on the third.

Xi Jinping has written (Qiushi No.7, 2010): ".. the productive forces are always the most active and most revolutionary force driving social progress."

Limits on traditional energy sources like fossil oil, and the people who control them, are the most important material factor limiting social progress in the world today, and threatening peace.

Oil causes more oppression today than before, because with more scarcity the price rises and “rent’ rises more, sending money to pay for oppression. But all fossil energy will rise until we succeed in a revolutionary transformation of all energy.

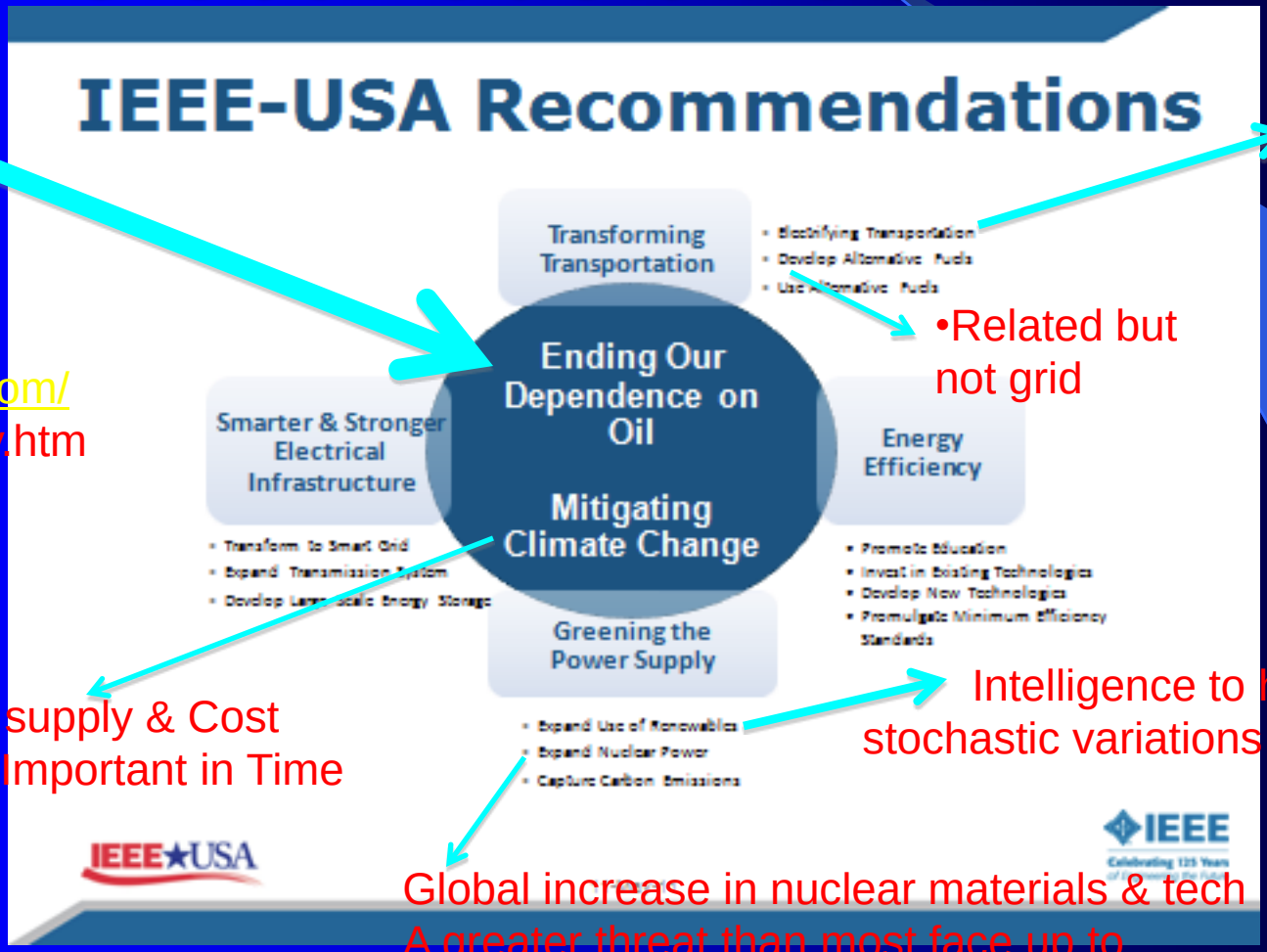
"NSF is currently supporting research to develop a '4th generation intelligent grid' that would use intelligent sytem-wide optimization to allow up to 80% of electricity to come from renewable sources and 80% of cars to be pluggable electric vehicles (PEV) without compromising reliability , and at minimum cost to the Nation (Werbos 2011)." -- NSTC (White House) Smart Grid Policy June 2011

Werbos 2011: IEEE Computational Intelligence Magazine, August 2011

Renewable Electricity Is ONE Important Battlefield In the War For Global Sustainable Energy

#1 Challenge Today Xi and Li

www.werbos.com/oil.htm, energy.htm



Switching & Intelligence To Allow More PEVs and Better Economics - S. Rahman

•Related but not grid

Coal supply & Cost Also Important in Time

Intelligence to handle stochastic variations across time

Global increase in nuclear materials & tech A greater threat than most face up to

Optimal Strategy for Total Energy Security

Maximize Fuel-Flexible Plug-in Hybrid Cars

Maximize supply of Alternate liquid fuels
– Not oil
– Incentives, standards and R&D

Open door to US natural gas (e.g. to trucks) while it lasts

R&D for more efficient use of diverse fuels

R&D for batteries for affordable electric cars

Minimize cost and then maximize supply of renewable electricity

Scientific Policy for Future Sustainable Electricity: Minimize ¢/kwh, Focusing on 4 Certain Nonfossil Sources Big Enough to Meet World Needs

- **Nuclear fission**: big now, but safe fission is about 10¢/kwh total, and sheer volume of nuclear material and technology is a key variable driving the probability we lose earth through conflict. A risk to survival, not worth the small net benefit.
- **Solar farms**: Stirling Energy Systems (SES) can soon lower US cost of reliable daytime electricity to 10¢/kwh. Considering best proven storage and transmission technology (CAES,LiIon) this sets an upper limit of 20¢/kwh total for earth. At 20,000 terawatts per year, this is $4 trillion/year. That is affordable but difficult. High cost is the biggest risk.

Scientific Policy (Continued)

- **Onshore wind** could meet all our needs, costing only 7¢/kwh at best sites, but is not reliable. In today's grid, total effective cost to end users is about 40¢/kwh.
- **ES** has two forms – one near certain to work, now estimated at 10¢/kwh, *if* key enabling technologies are developed. The other shows great serious hope of 5¢/kwh or less.
- The combination of SES and ES would require much less storage, because SES is daytime and ES is 24 hours/steady. This allows 10¢/kwh overall, reducing the cost of a sustainable global system from $4 trillion/year to $2 trillion/year, as cheap as fission without so much risk.
- More efficient and scientific R&D on ES, solar Stirling, grid/storage and new high risk low cost options would probably cut the costs in half again.

Early History of ES in USA

- Focus on Space Solar Power (SSP), a form of ES proposed by Peter Glaser in Science
- Designs from big companies ≈≈1977-1980 did not pass DOE/NASA technical evaluation (Koomanoff, me)
- New designs from NASA SERT program under John Mankins did pass strenuous technical evaluation. See National Academy of Sciences report cited by…
- NSF/NASA joint funding of SSP in 2002, led by me and Mankins. Search on "JIETSSP" at www.nsf.gov.

What We Know Today About SSP

- From 2002 NASA/NSF review meeting: the best full life cycle cost estimate, a careful best practices engineering cost estimate from SAIC, showed 17¢/kwh for the best fully validated SSP design, under certain **aggressive assumptions** about future space technology, based on inputs from NASA as at http:/paul.werbos.googlepages.com/IvanBekey.pdf.
- Mankins has studied the cost drivers of that design, and located new enabling technologies like proven new heat pipes which almost certainly reduce it to **10¢/kwh under the same assumptions.**
- New materials and electronics offer a number of serious possibilities to cut it more through R&D.

Space Fusion Power (SFP) – A Second Promising Form of ES

- As an electricity source for earth, first proposed by me in State of the Future 2003, 2004.(www.stateofthefuture.org.)
- Use high power lasers in space, powered by concentrated sunlight, to drive fusion in pellets made mostly of deuterium, as designed by John Perkins of Livermore. Use magnets in space to transform proton currents to lower voltage electricity, beamed to earth by microwave or laser.
- The fusion acts as a kind of amplifier of the solar power by a factor of more than 100 – 100 times as much electricity for only double the capital cost. Maybe cheaper than on earth, because no heat reactor or capacitor bank needed, and sunlight is more intense and 24-hour in space.

Key Needs For Action I

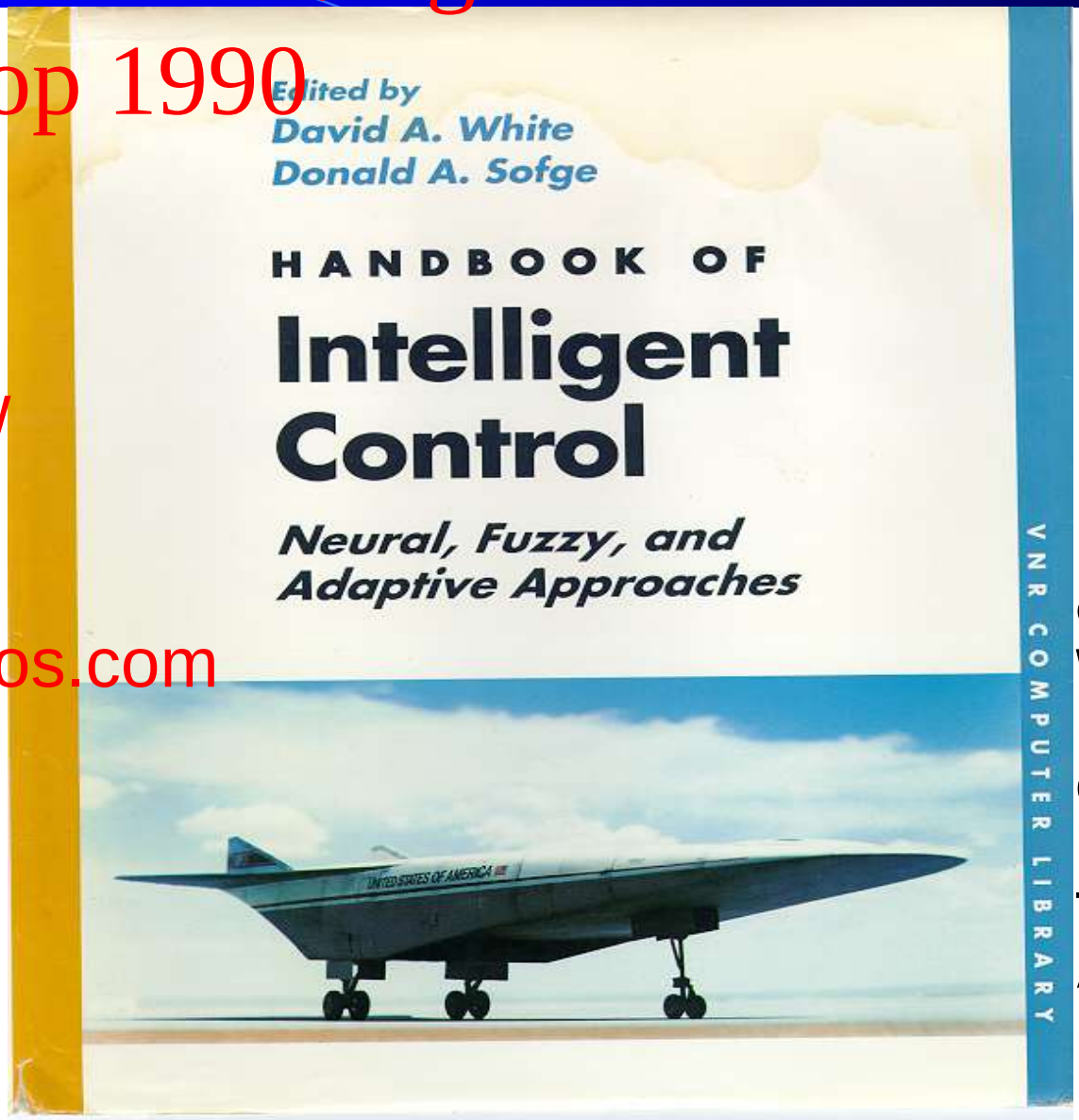
- Most urgent: make 10¢ and 17¢ SSP designs "really available" by developing, deploying and proving all the "Bekey assumptions," focusing first on those which seem most uncertain, and trying to do even better if possible.
- Most urgent by far: develop the assumed $400/kilogram access to low earth orbit (LEO). It does not matter to humanity who does it, but if we do not act soon, it may become very difficult, because we have a problem with crucial endangered technology.

Key Needs For Action II

- Perform full best practices engineering cost estimation, with variations in design to look for the best, for Mankins' new concept. Once we have more confidence that we can get to 10¢/kwh or better, much larger investments become justified.
- Initiate a world R&D competition, perhaps at $100 million per year to start, to aggressively explore the deepest possible cost reductions in SSP and SFS both (including laser development). The structure for about half of this should be similar to the joint ARPAE/NSF proposal at www.werbos.com/energy.htm. About half should be for more mature technology readiness levels, an area which Mankins is the world's expert on.

How minimize $/kg-LEO?: NSF/McAir Workshop 1990

Just a Few Chapters Posted at www.werbos.com

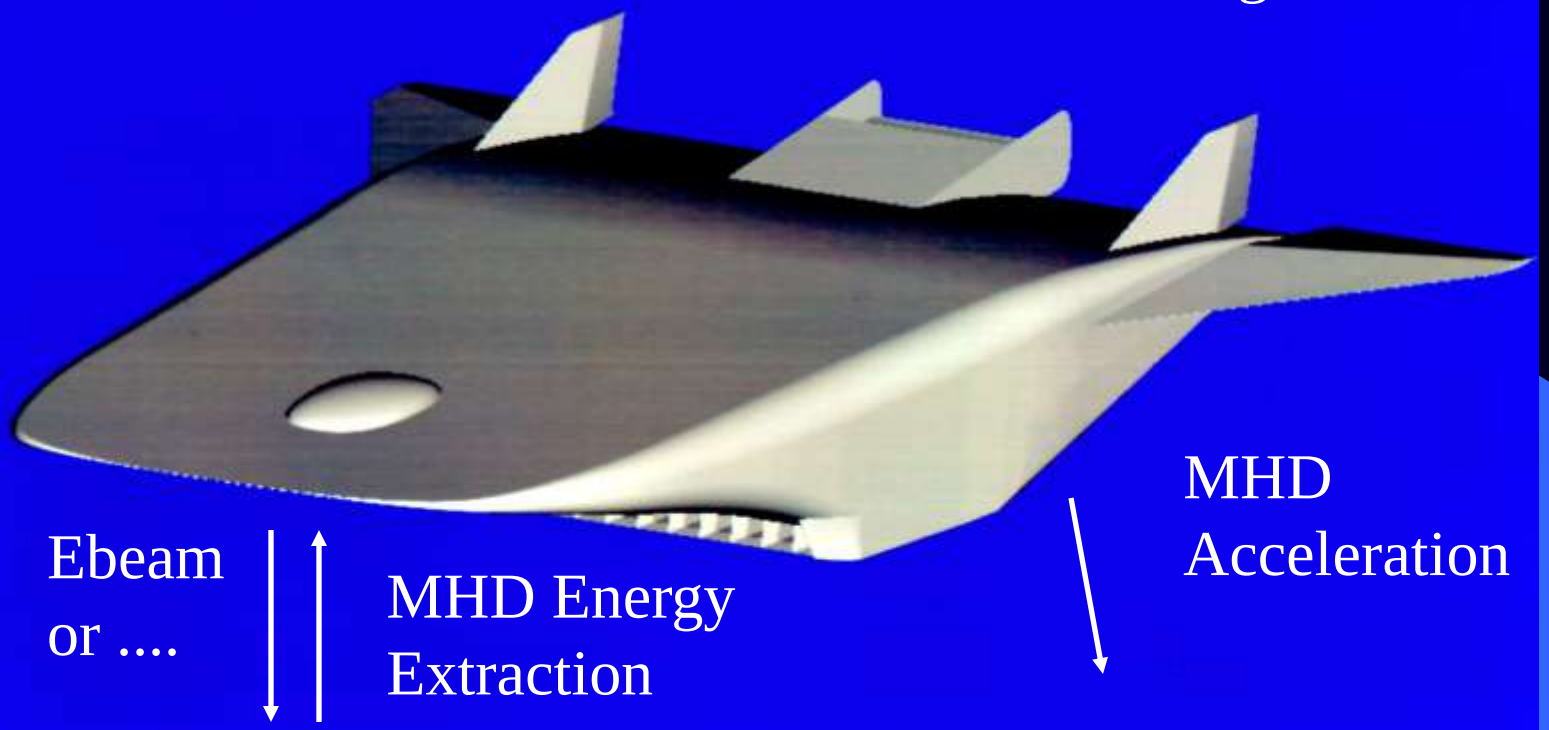


McAir work on NASP – World's Most Complete Effort To Make Airbreathing Launch Real.

White and Sofge eds, Van Nostrand, 1992

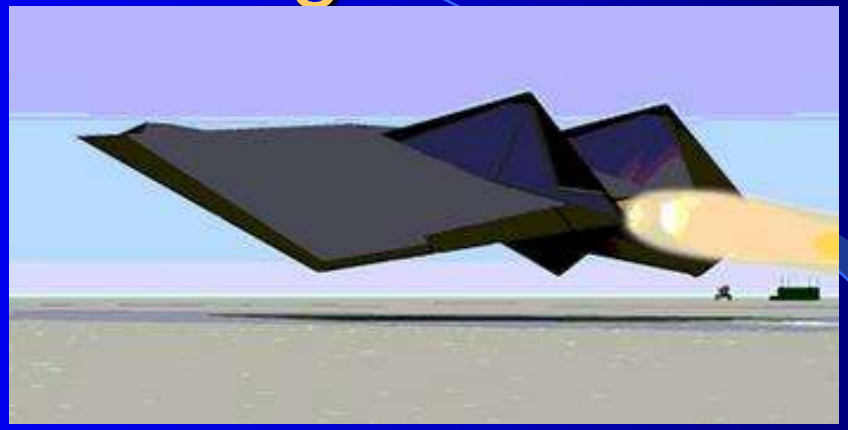
NSF-Funded work at ANSER and AAC validated Russian claim that plasma improves airbreathers

REDUCED DRAG: AAC 1st; Ganguly (APS00)shows it should work >Mach 4, 100K feet; allows Boeing RAS/V



Best plasma theory now predicts new Princeton design will allow ramjets to reach Mach 12, scram much more... Ames and Chase (ANSER) whole-system SSTO designs..

Unexpected Outcome: Near-Term Design Has Passed Tough Peer Review, Scrutiny



- Rocketplane RLV can be built now for near-term use, essential to use/enhancement of endangered off-the-shelf legacy technology needed for more advanced high-efficiency concepts
- Need Big vehicle to minimize $/kg (initial $400/kg REAL)
  - 1.2 million pounds, $10-15 billion, not a small business
- Horizontal takeoff essential for aircraft operations (see also Mueller 60's) and for big-wing lower heat load on re-entry
- Design allows use of formerly black hot structures technology instead of flaky tiles, ablative structures, hard-to-control slush
- Project chart 4 years, AF mission model enough for profit

Final Thoughts on $400/kg-LEO

- The technology described by Chase is very different from technologies like batteries where China can get ahead by itself. Chase's unique systems-level hypersonics knowledge, Boeing's hot structure and TAV and RASV technologies, and maybe my own questions (as in the Ajax experience) are
  - Endangered as key people age and retire
  - Requiring some kind of partnership deal which USGOV and Boeing would accept. E.g. joint funding for a launch services concept, with a private company developing the launch capability.
- To keep the option alive, and have more security, most urgent are:
  - The $2 million design study Chase has proposed, which we almost funded…, perhaps with another $2 million for a parallel effort in the same general space
  - A $30 million to $150 million hot structures test project. (Active thermal protection systems are assumed good enough in much US research, but the weight of the best TPS killed NASP. True C-C is too expensive.)
- Cost per kg-LEO is a crucial driver of all space activities. E.g., at 1/10 launch cost, the same money buys telescope ten times as heavy. Enough to truly see other planets within 1000 light years.

Final Thoughts on International ES

- Policy makers need to understand more completely how availability of ES electricity worldwide in other nations is of urgent importance to their national security, as well as global development. For example, if many nations are forced by economics to produce more nuclear material, we are all at risk. The need for an alternative is urgent. Also, ES could let us reduce CO2 emissions much faster worldwide – CO2 is a global problem.
- To achieve this goal, an international consortium to run the power plants and sell the electricity worldwide is essential.
- Still, it may be possible for the new consortium to buy launch services from a narrower entity, which it helps to create. If not, perhaps India or Russia could help China relearn what Boeing is at risk of losing.