

# Heat to Electricity: Lessons from Earth Based Technology

- 2010-14 White House Mandate; now SERC, IEEE
- Earth markets: very diverse, location, time of day
  - Latin America best solar farm options, needs wires
  - SSP huge need in Japan, Korea, far north...
- Solar thermal vs PV in Chile: huge progress Heat to Electricity Core technologies:
  - Here now: thermocouples (space), Stirling 1, Brayton\* 3
  - Key R&D: Stirling gen2, gen3; JTEC; Q

\*Google “Brayton Energy”

“NSF is currently supporting research to develop a ‘4<sup>th</sup> generation intelligent grid’ that would use **intelligent system-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).”

(search on White House smart grid 2011)

**\*[www.werbos.com/E/GridIoT.pdf](http://www.werbos.com/E/GridIoT.pdf)**

# How much does electricity cost?

Average national electricity prices in US cents/kWh (2011)

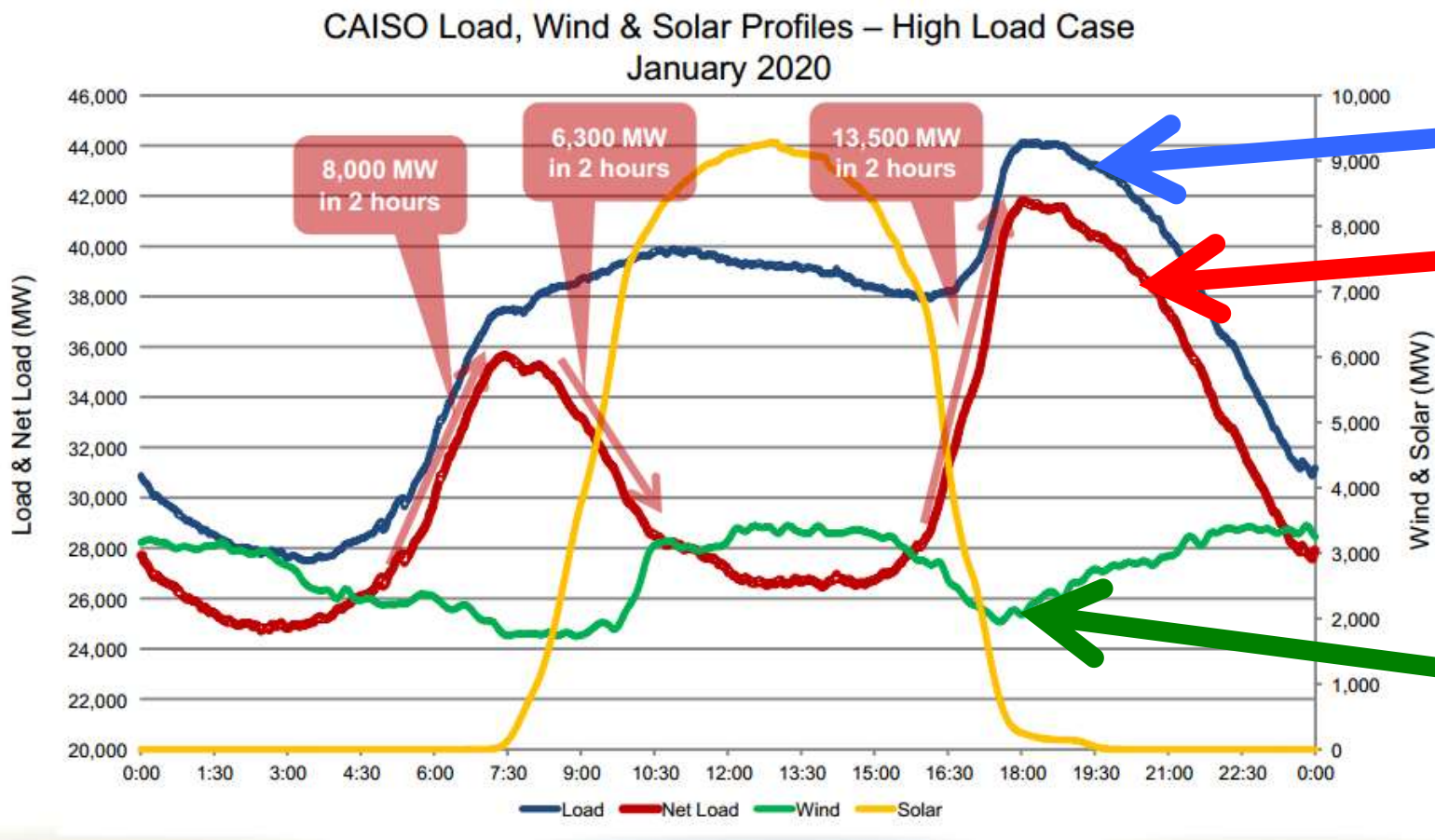


Data: average prices from 2011 converted at mean exchange rate for that year

Sources: IEA, EIA, national electricity boards, OANDA [shrinkthatfootprint.com](http://shrinkthatfootprint.com)

- US and EU are already above 10 cents per kWh. China is less, but heavily subsidized, encountering shortages and price rises with coal (not counting CO<sub>2</sub>)
- OECD/IEA: world uses 21 thousand terawatt hours per year (2011). At 10 cents per kWh, that is worth **\$2 trillion per year**. With wind or solar supplying all, that would double or more. (Storage needs, backup, regulation.)

# Time of day and predictability are crucial



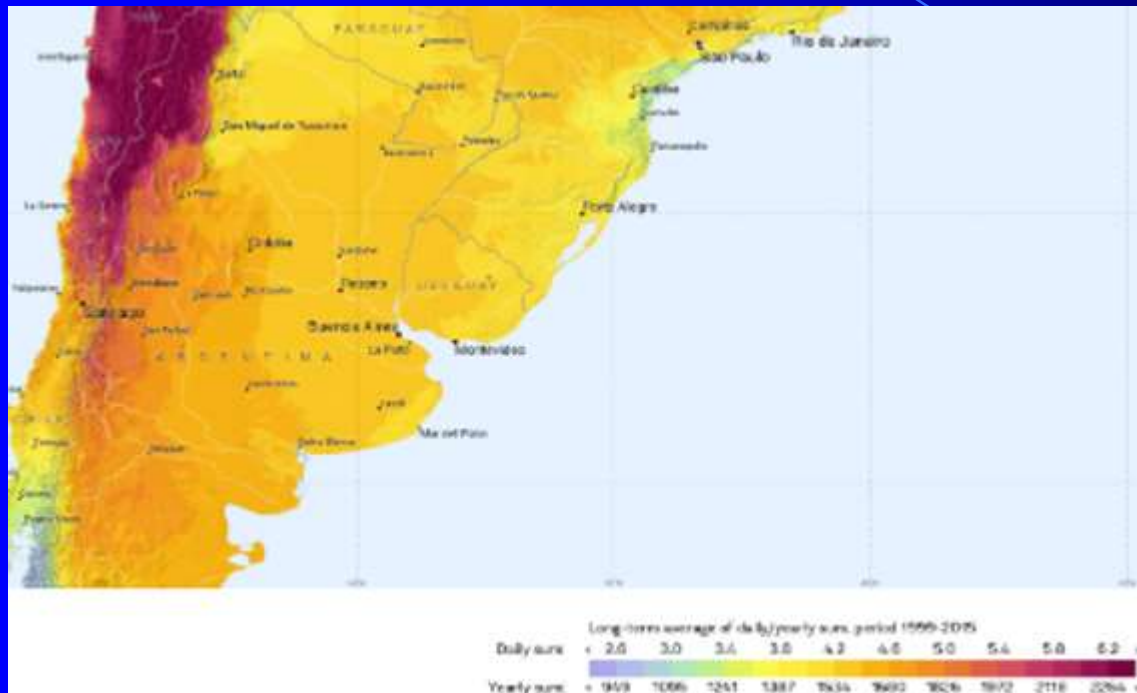
Demand

Demand  
Minus  
2020  
solar

Wind

- Chile and Brazil have unique hydro base, so intelligent timing of its use avoids need for more storage
- Most of rest of world faces tricky choices, 10¢ extra

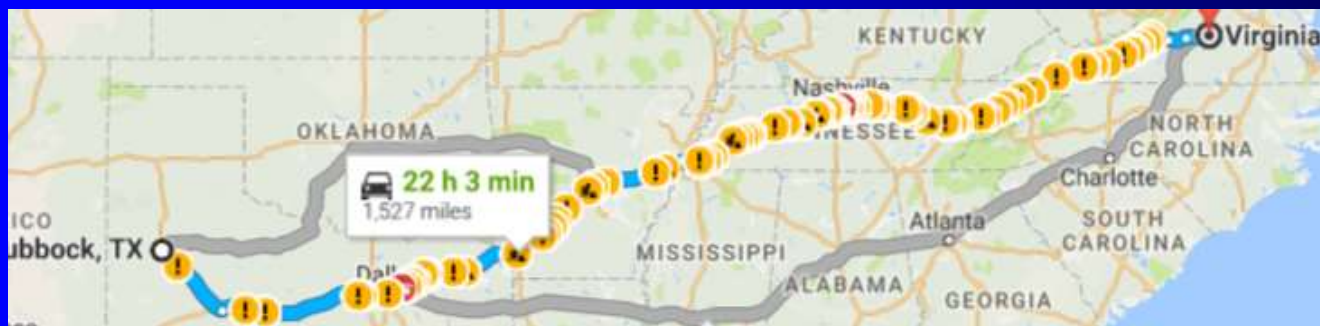
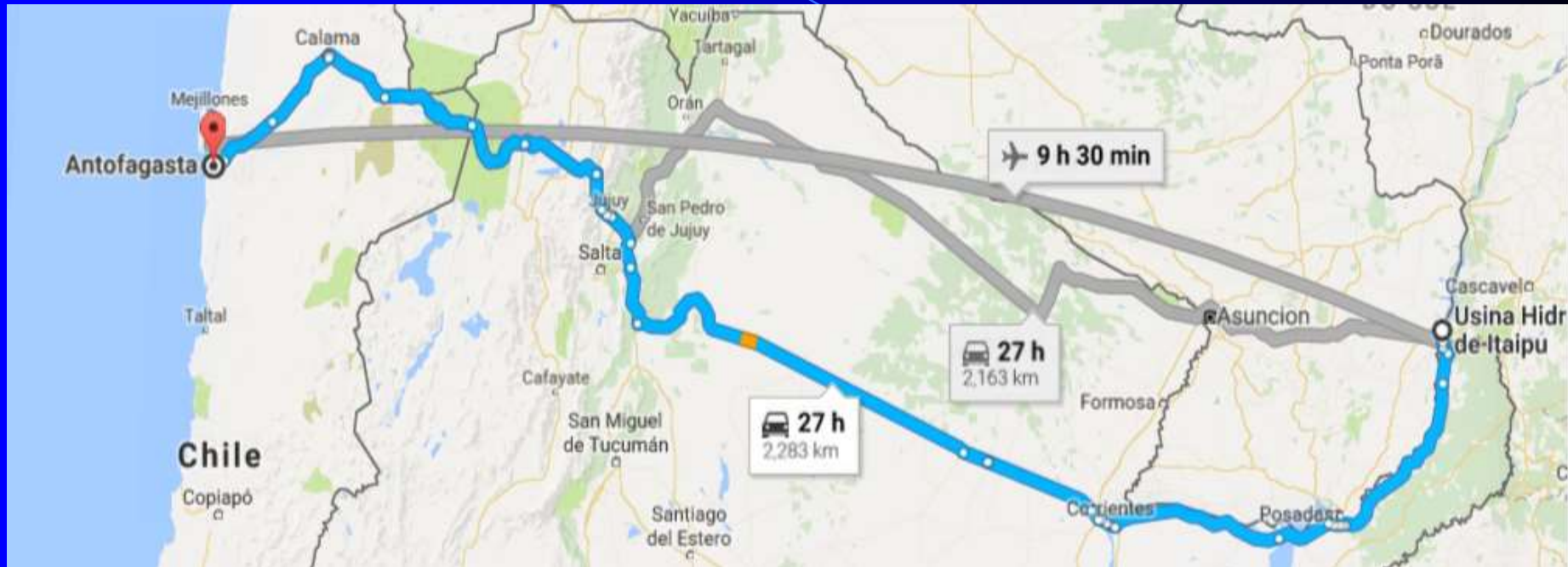
# CTG Already Invests in Renewables in Brazil. Why Go to Chile?



Source:  
SolarGIS

- Because cost per kwh is half as much when sun is more than twice as strong, for any technology.  
 $5¢/\text{kwh} + 2¢/\text{kwh} < 10¢/\text{kwh}$ , difference worth \$30 billion on \$100 billion. (Add 2¢ in Brazil anyway.)

# Proposed Start: 10 gigawatts on new line as long as TX→PJM 2¢/kwh



1gw→2.8TWH/year. With  $(10¢-3¢-2¢)*28TWH$ ,  
\$1.5 billion/year extra profit on \$3b investment

# GEF 2006: Three Types of Solar Thermal Solar Farm, All AC

- Already proven,  $\geq 20\text{¢}$  in US:
  - Giant troughs using much water
  - Power towers: little mirrors focus on “eye in the sky”: new way to make synfuel (UNH)
- Unproven leadership opportunity, solar orchards:
  - Each “tree” stands on its own, moving reflector points to small Stirling engine. (Sandia/STM)



# Why Solar Orchards Probably Cost Less

- Sandia/NASA/STM estimated 5-7¢/kwh in mass production, assuming more efficient Stirling engine. Can be scaled up quickly, no new factories necessary. (Existing engine, body factories, etc.)
- Stirling Energy Systems (Sandia) estimated initial 12¢/kwh for 750-megawatt plant actually under construction, with old 30% engine, until legal orders to stop.
- Under new Chinese owners, STM is expanding but still relies on 30% efficient engine.
- Lennart Johansson, co-inventor of Stirling, has new..



**2016:** 3¢/kwh PPAs based on solar cells probably safe at 10 gigawatts, but need hedge to secure the path to \$100 billion/year (i.e. be sure of <8¢/kwh)

- Power towers have sold 12¢/kwh technology, but 6¢ cents is in the pipeline
- Unproven leadership opportunity, solar orchards:
  - Each “tree” stands on its own, moving reflector points to small Stirling engine. (Sandia/STM)



# How can we be certain we can get $\leq 5\text{¢/kwh}$ PPAs up to 30gw?

- Atacama already had  $3\text{¢/kwh}$  in 2006, with PV farms, and storage not needed to Brazil. But:
  - Trump claims panel costs will go up,  $9\text{-}10\text{¢/kwh}$ , after China stops dumping solar panels\*.
  - China-based funds may disagree, and may like to create a big new market for their solar panels
- Solar Reserve soon bids  $5\text{¢/kwh}$  for Atacama CSP, with storage, simply by advances studied in DOE/NREL sunshot program. But not proven yet.
- As in 2016, major **new unmet** technology options worth \$30 million hedge in a \$3 billion investment, updated\*.

\*[www.werbos.com/E/GridIoT.pdf](http://www.werbos.com/E/GridIoT.pdf)

# Opportunity for Gen 2 Stirling



- Lennart Johansson, co-inventor of the 30% engine, was STM chief scientist
- He now has credible technical plan to produce 50% engine, for affordable mass production in existing plants.
- The engine can be used in solar orchards but also to process waste, waste heat, and in cars and trucks, where it offers fuel flexibility, whole cycle
- Cost to demo manufacturable 50% for waste or cars: \$1 million “first tranche.” \$10 million for solar tree demo with mass-producible “trees.”

# Gen 3 Stirling

- Al Sobey, former GM Division Director, leads group with patent on new compressor, which, like Brayton 3 turbine, gets rid of pistons
- Inverting it, with modern manufacturable materials for efficiency and heat pipes, suggests 50-60% efficiency versus small Brayton only 36%.
- Search on ("PDT LLC" Brock) for clues
- Sobey knows how small retooling of existing underused auto engine factories could mass produce their designs in about a year if go ahead...

# JTEC Johnson R&D

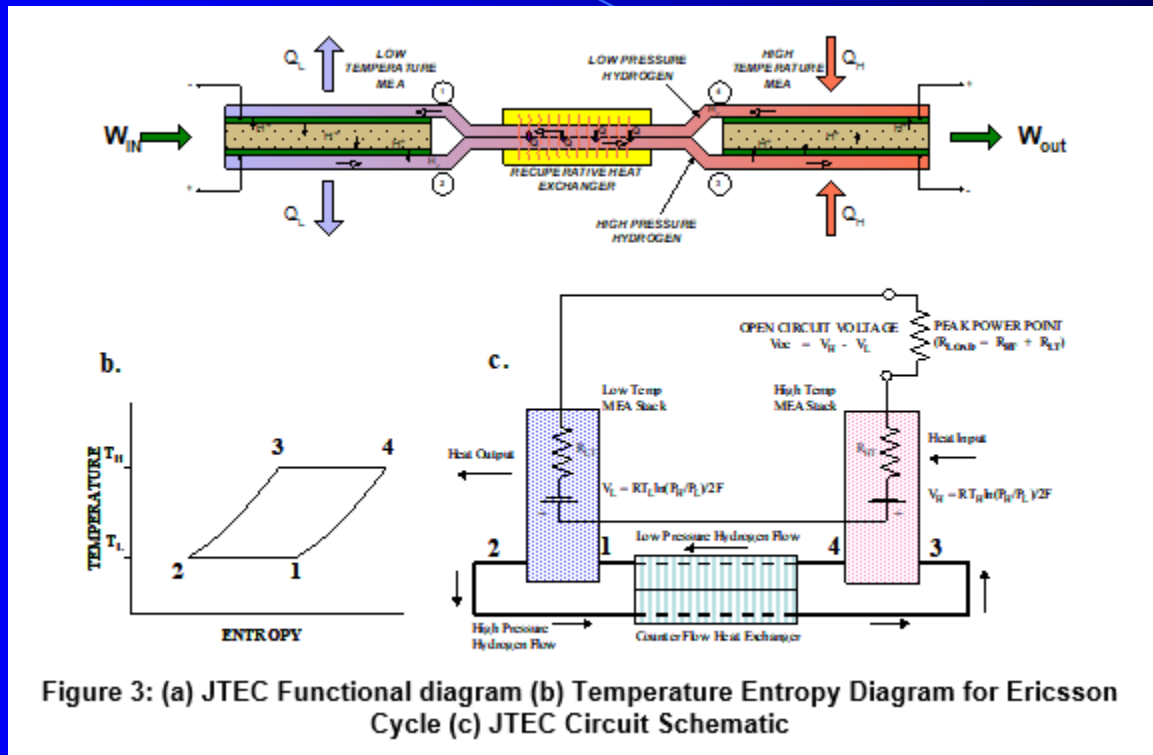


Figure 3: (a) JTEC Functional diagram (b) Temperature Entropy Diagram for Ericsson Cycle (c) JTEC Circuit Schematic

- 50% risk, high potential
- No solid moving parts, has had NSF and NASA \$
- Needs work but simulations show might get 70%





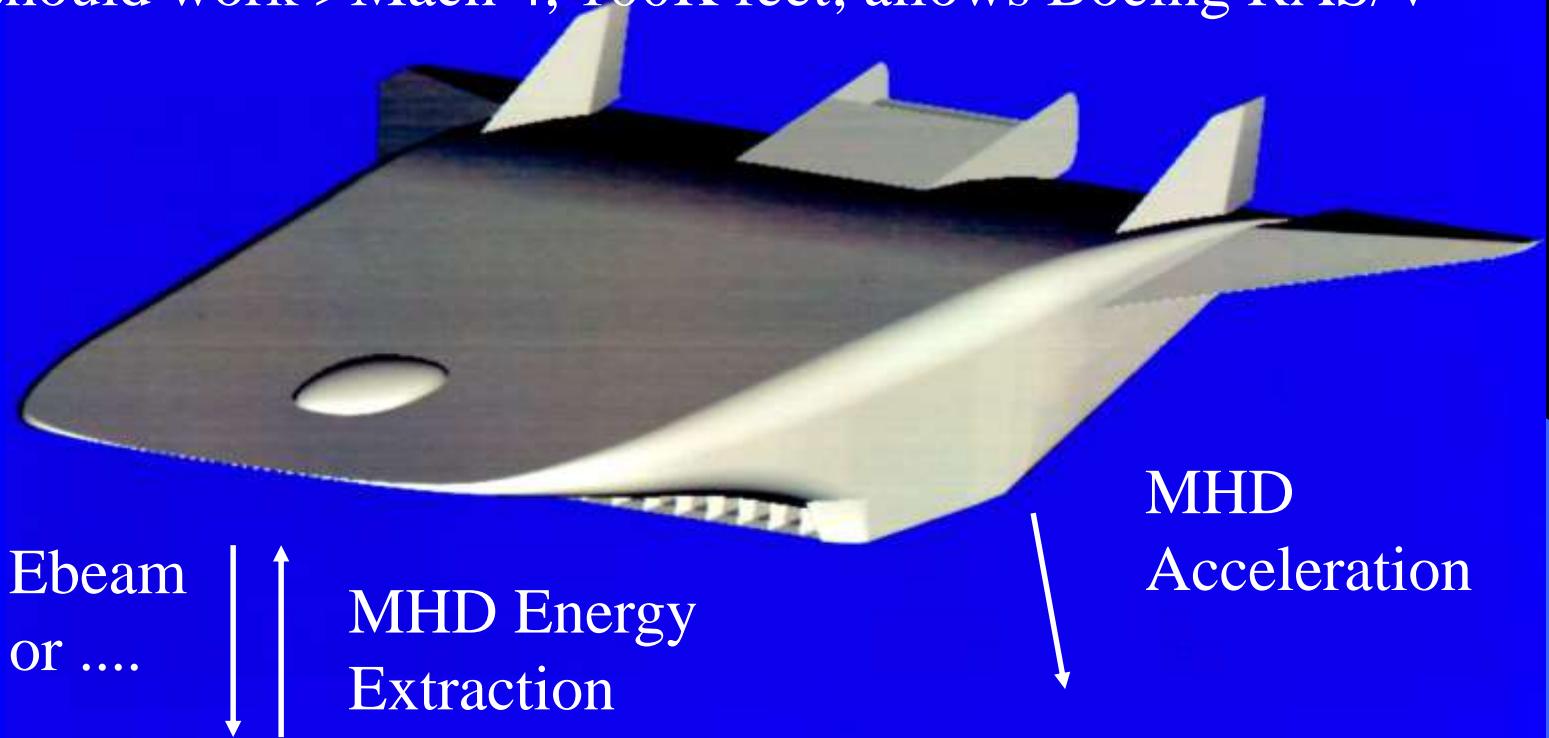
- **Links from [nss.org/EU](http://nss.org/EU):**

- **NIAC Report:** New Design for 9¢/kwh if launch costs down to \$500/kg-LEO
- **DARPA XS-1** Technology could get us to  $\leq$ \$500/kg-LEO

See my detailed review  
in *Ad Astra*,  
summer 2014

# Plasma Hypersonics: ANSER/Chase NSF\$

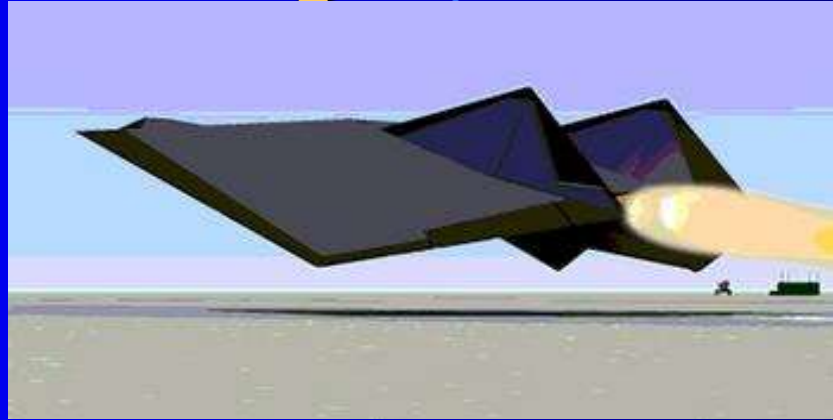
REDUCED DRAG: AAC 1st; Ganguly (APS00) shows it should work  $>$ Mach 4, 100K feet; allows Boeing RAS/V



Best plasma theory 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



- Advanced RLV designs require use/enhancement of **endangered** off-the-shelf legacy technology
- Need Big vehicle to minimize \$/lb (initial \$200/lb **REAL**)
  - 1.5 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



AI



Bio e.g. BCI

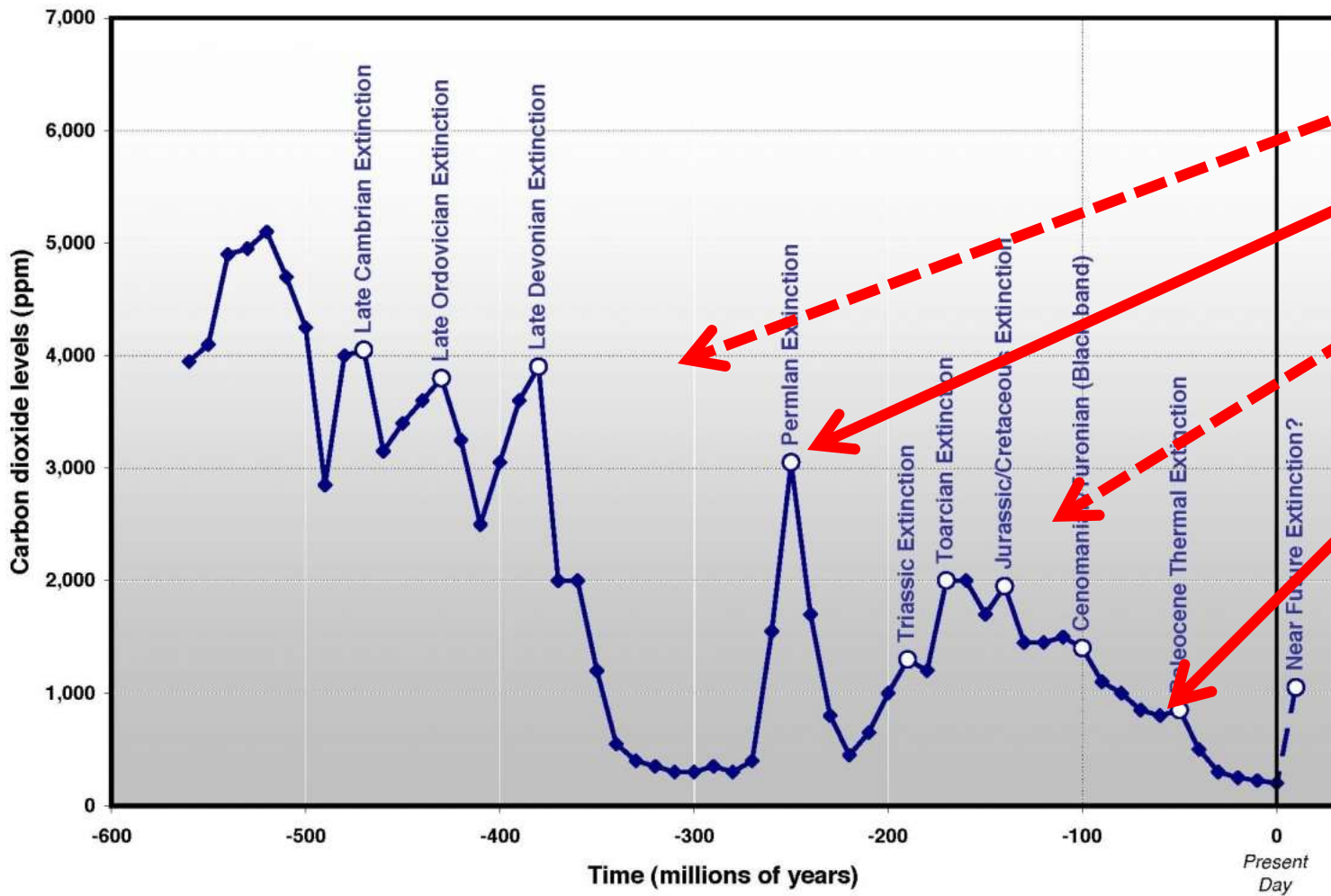


H2S, Climate



WMD+

**Lifeboat Foundation Studies:  
Extinction of Human Species  
Quite Possible if Top Decision  
Makers Unconsciously  
Assume and Implement  
Obsolete Paradigms for IT!!!**



H2S in air  
And  
Radiation  
Enough  
To kill  
All humans

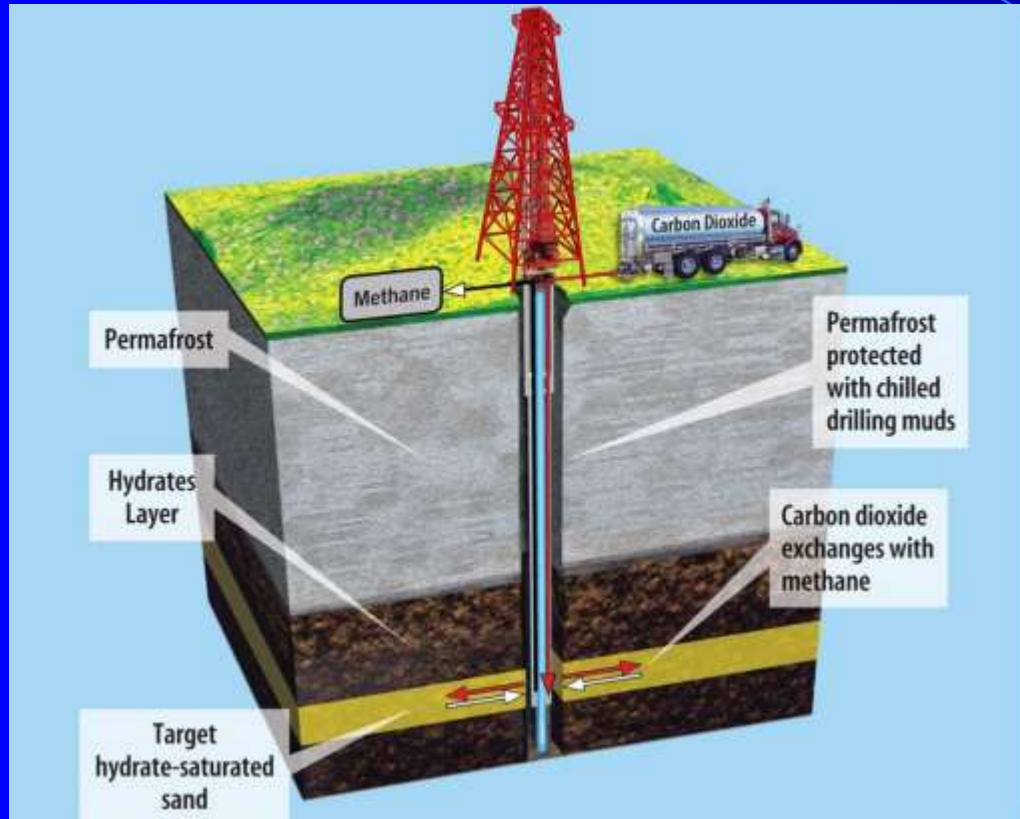
- NSF Geosciences sponsored best data on past:
- Graph from Peter Ward, Under a Green Sky, adapted by Englander. Ward theory half right.

# Will Euxinia Kill All Humans? How Big is the Risk, How Soon?

## Dr. Paul J. Werbos

- Research Program Director, National Science Foundation 1988-2015 (“AI”, power grids, quantum)
- Detailed to Senator Specter/EPW in 2009
- Search on “Werbos” at youtube
- Still active in IEEE and many other professional groups like Chile Solar Energy Research Consortium

But in 40-100 years, Ward's gut might prove true if this continues...



Big new push in China. Unlike biofuel, clathrates 10-20 times as much GHG per energy, to atmosphere or, worse, to ocean euxinia direct (anoxia in Pacific direct to South China Sea).

We are in a race!!!!

Image credit: Live Science