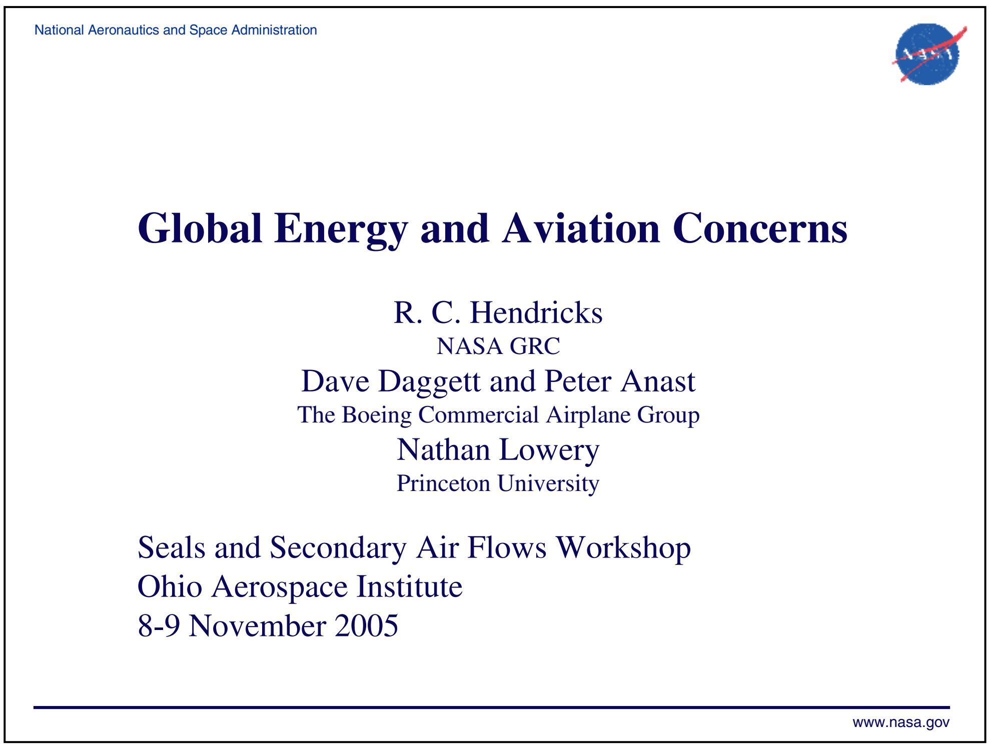
GLOBAL ENERGY AND AVIATION CONCERNS

Robert C. Hendricks
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

Dave Daggett and Peter Anast
The Boeing Commercial Airplane Group
Seattle, Washington

Nathan Lowery
Princeton University
Princeton, New Jersey

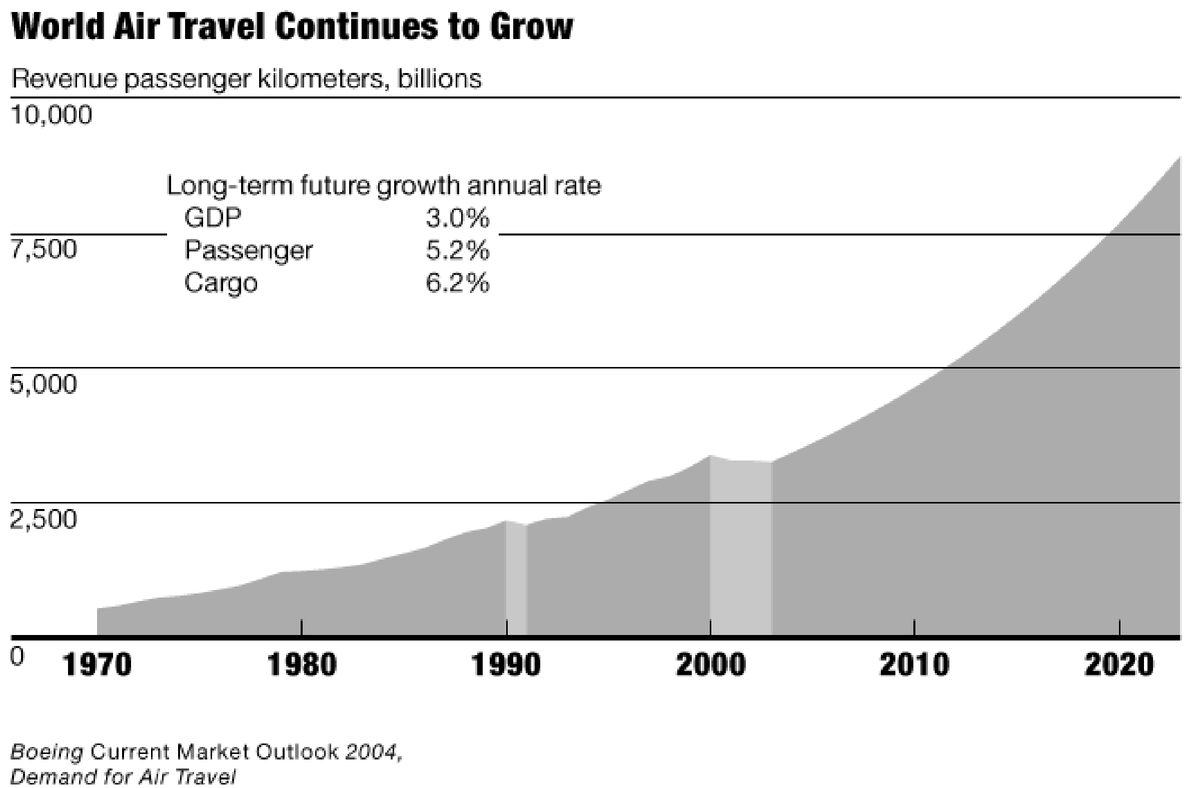


Windows of Opportunity

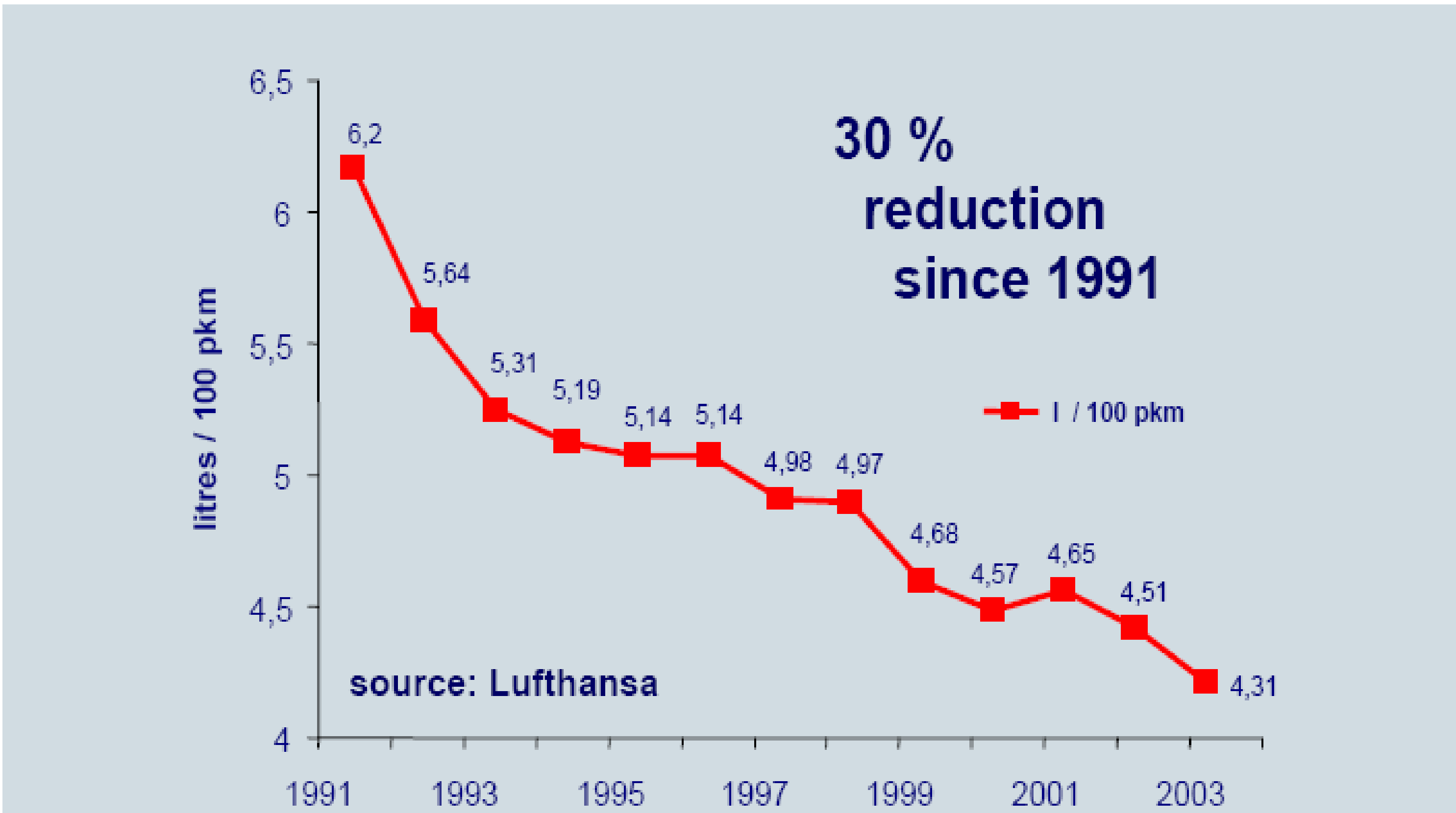
- From time to time we feel it necessary to draw your attention to changes that we feel will affect the seals and secondary flow community. In the past we have cited changes and needs in technical direction in several areas such as :
- Dr. Keith cited our Navy-NASA seals conferences and out of them grew a community of understanding under the leadership of Larry Ludwig. And from this community came the ***Self-acting Face Seal*** as well as a greater understanding of face seals use in engines.
- Attention was then turned to Rocket Engines for the Space Program and required the development of ***Cryogenic Sealing*** and applications.
- With the advent of the very high power-density Space Shuttle Main Engine came the need for understanding of the ***Rotordynamics of Turbomachines***
- The complex interaction between sealing and secondary flows required more accurate and validated methods for design and the codes ***SCISEAL, INDSEAL*** and ***SCISEAL-TURBO*** were developed to meet these needs.
- We cited that future demands of ***Anthropogenic Global Emissions and Control*** would become major issues and major opportunities for the sealing and secondary flow community.
- With the development of new seals and emissions demands, we then cited the needs for ***Reliability and Life and Field Data Feedback*** for design support and integration into our codes.
- Today we want to draw your attention to ***Global Energy and Aviation Concerns***.

✓ For references, see Seals and Secondary Air Flow, and Rotordynamic Instability Problems in High Performance Turbomachinery Workshops as cited in **NASA/TM—2004-211991/PART1, PART2, PART3**

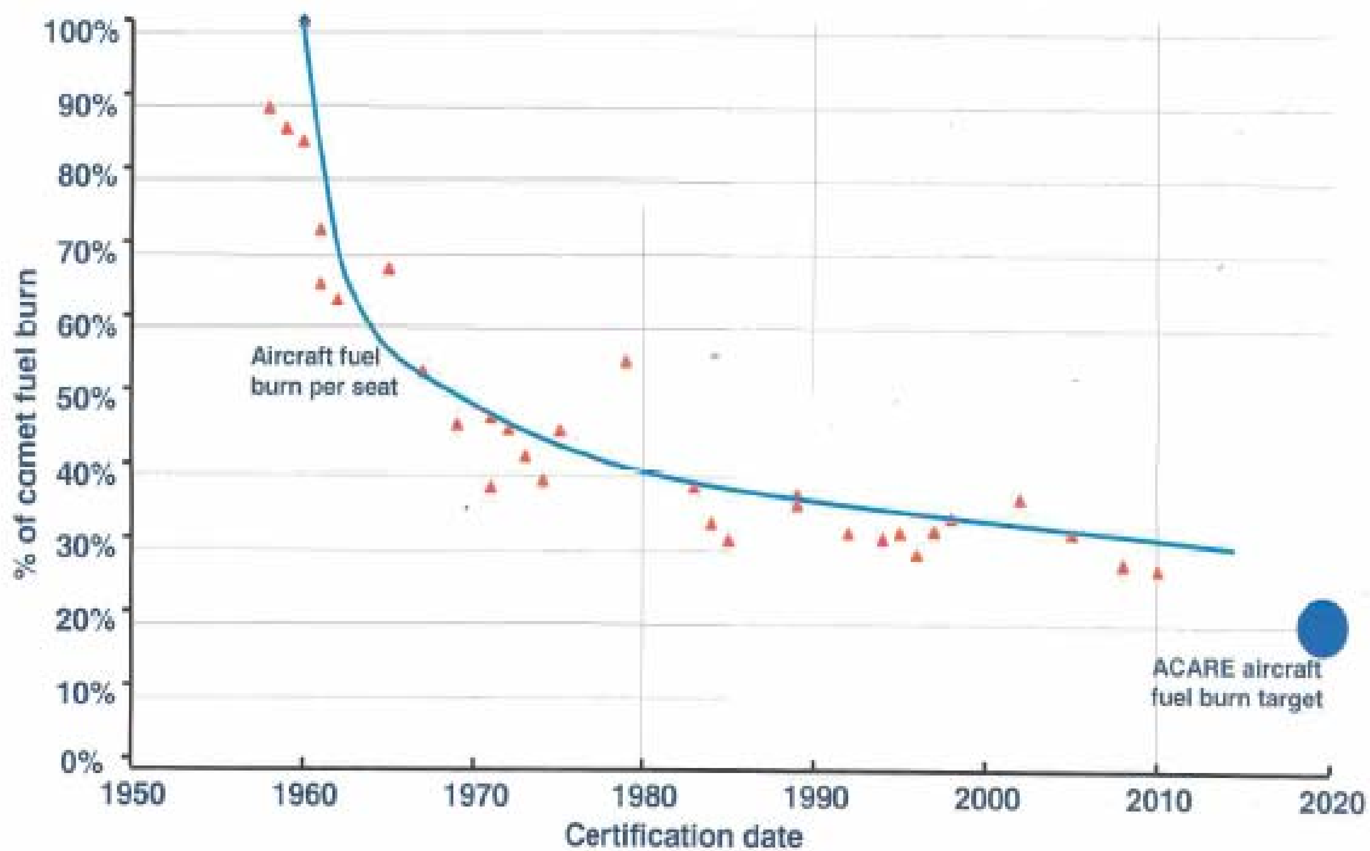
Air traffic is expected to grow at least 5% per year [Daggett (2005)]



Fleet fuel consumption (liter/passenger-km) shows 30% reduction since 1991, Broichhausen (2005)



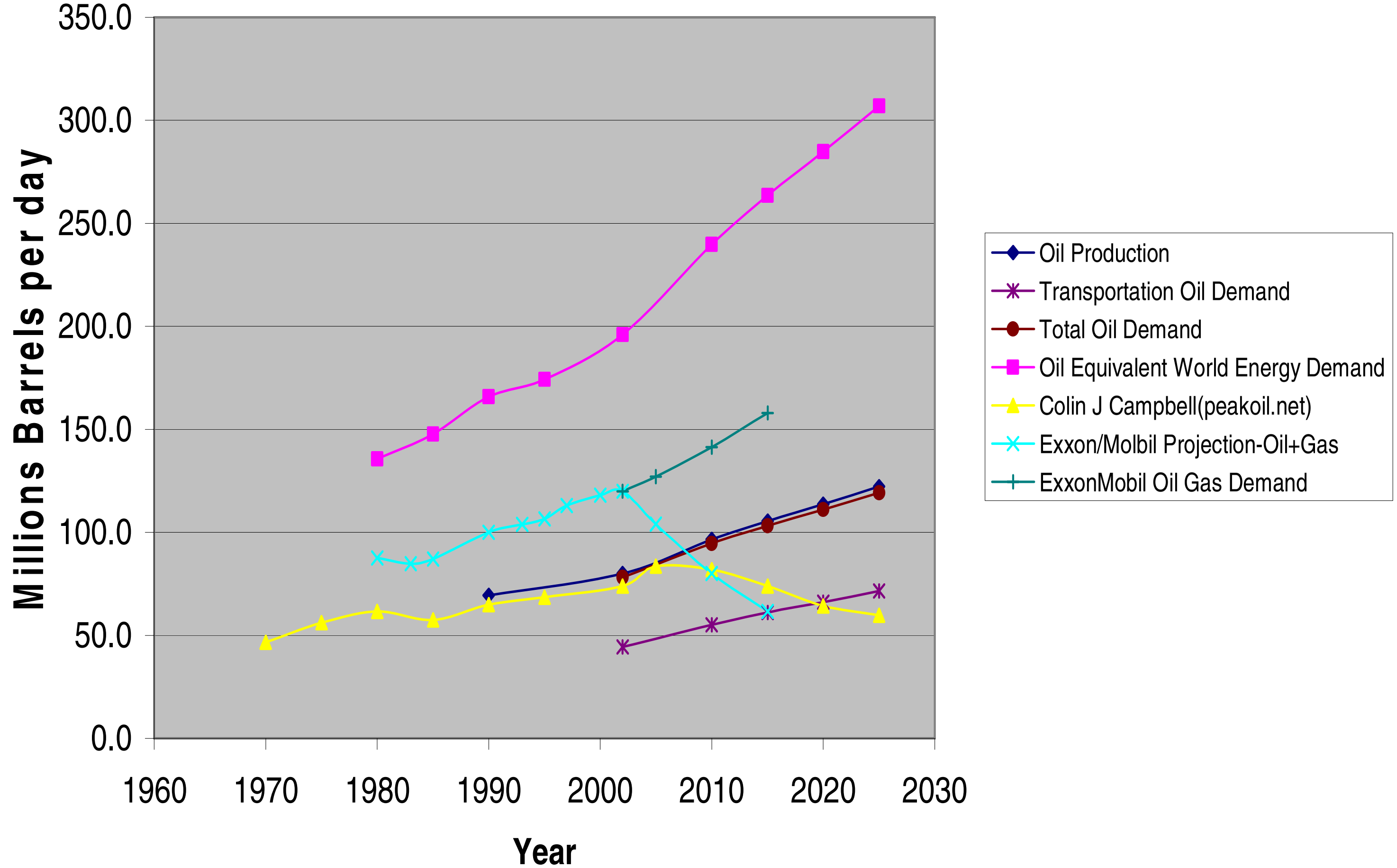
Fuel Efficiency Improvement of Long Range Transport Aircraft: Reduce (2003)-fuel burn 50% , Smith (2005).



Investment and Cost of Growth

- We select air travel as it is of interest to the NASA Aviation Program, yet our concern permeates the transportation and industrial power generation community as well and hence the full spectrum of sealing and secondary flows.
- Air travel is projected to return to its pre-911 growth of 5% per year.
- In some areas (Asia Pacific Rim) this growth is already at 14%
- We are doing well reducing total fuel burn in terms of liters of fuel / passenger-km and aircraft efficiency has been reduced but is nearing a plateau (EU 2020 goal: reduce fuel burn long-range aircraft 50%)
- But here are some of the problems we face.
- Our total energy demand is projected to rise nearly linearly over the decades while our energy supply for transportation (oil) declines.
- Our nation's economic and military security depend on oil.
- The current production of oil appears limited to 84Mbbl/day and would require significant capital investment of $16 Trillion to meet these demands for oil.
- The problem is that oil availability is limited and it is not a question as to if we will run out of "cheap oil" but when.
- Most of the proven oil reserves reside in the middle east with 2/3 in Saudi Arabia.
- Rapidly rising foreign interests in oil and natural gas have expanded foreign presence and heighten potential for conflict.

World Energy, Oil/Gas and Transportation vs Production Reality [Source: EIA and Others]



Oil consumption

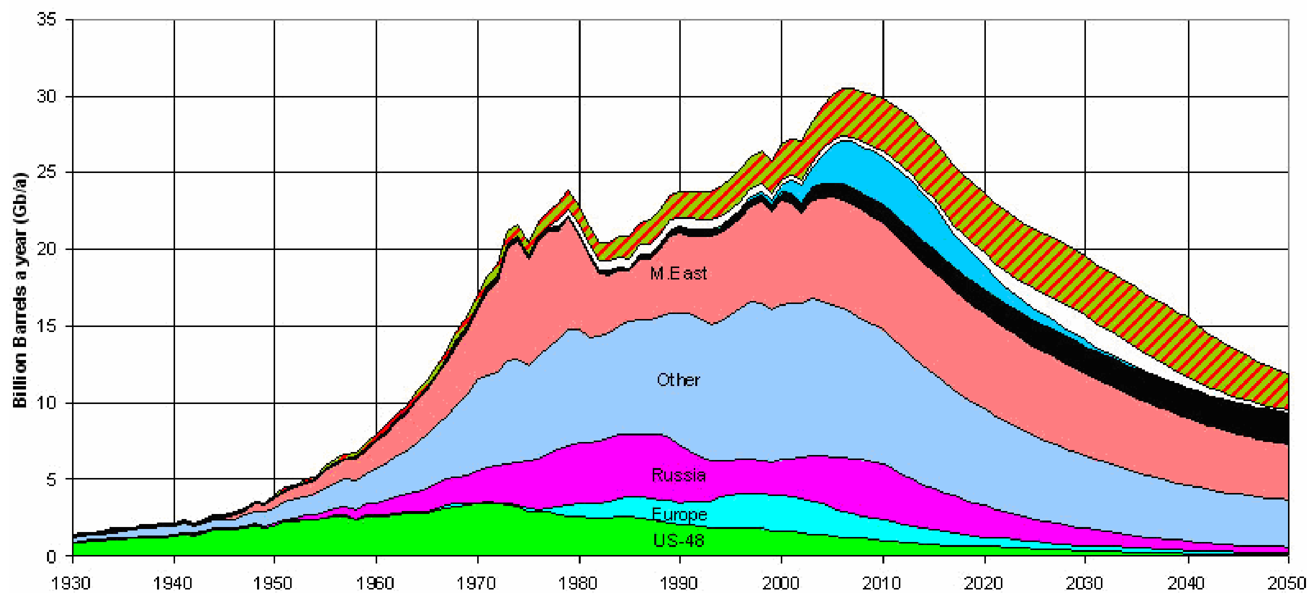
http://www.peakoil.net/uhdsg/Default.htm

Uppsala Hydrocarbon Depletion Study Group

OIL AND GAS LIQUIDS 2004 Scenario

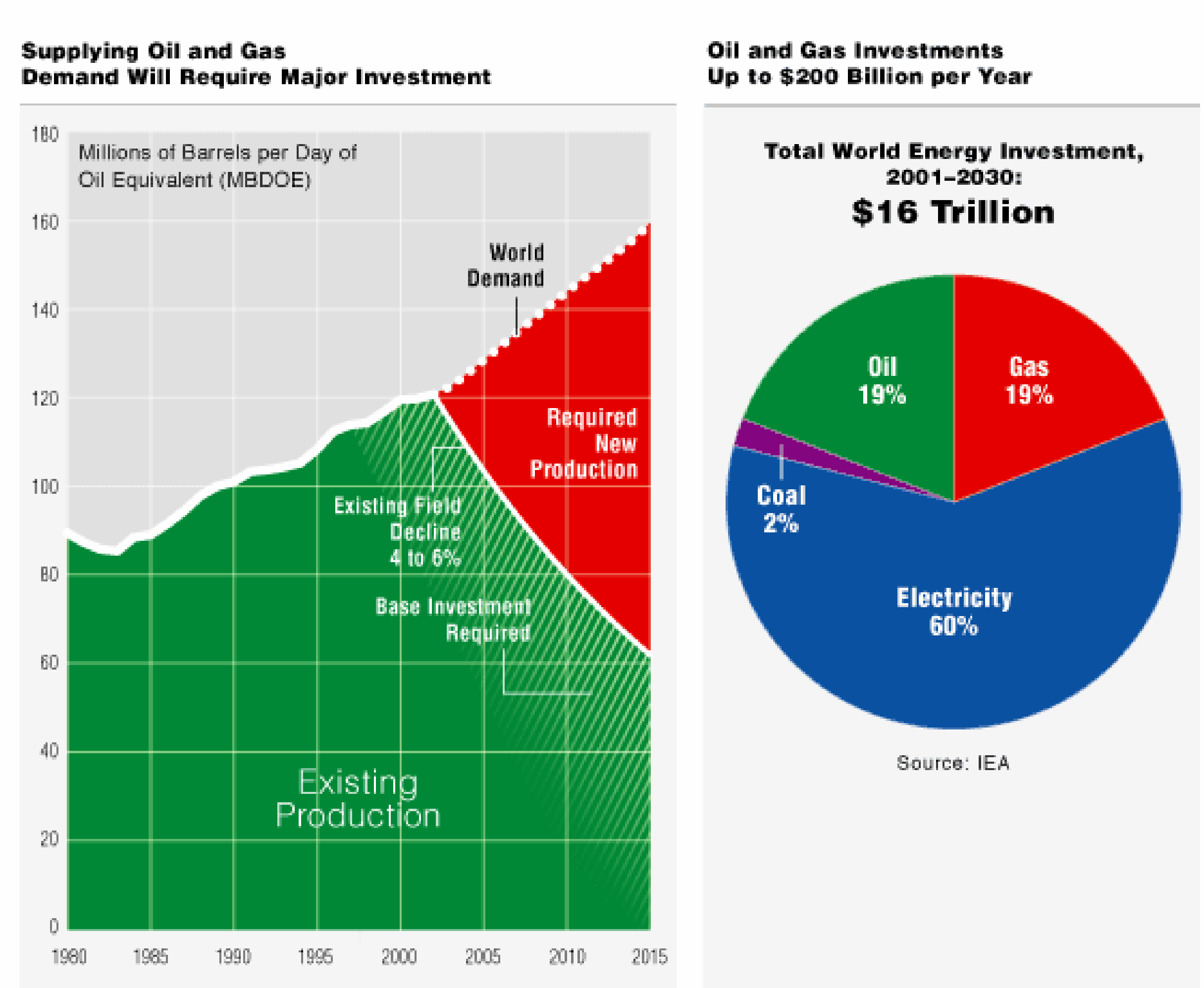
Updated by Colin J. Campbell, 2004-05-15

OIL AND GAS LIQUIDS
2004 Scenario



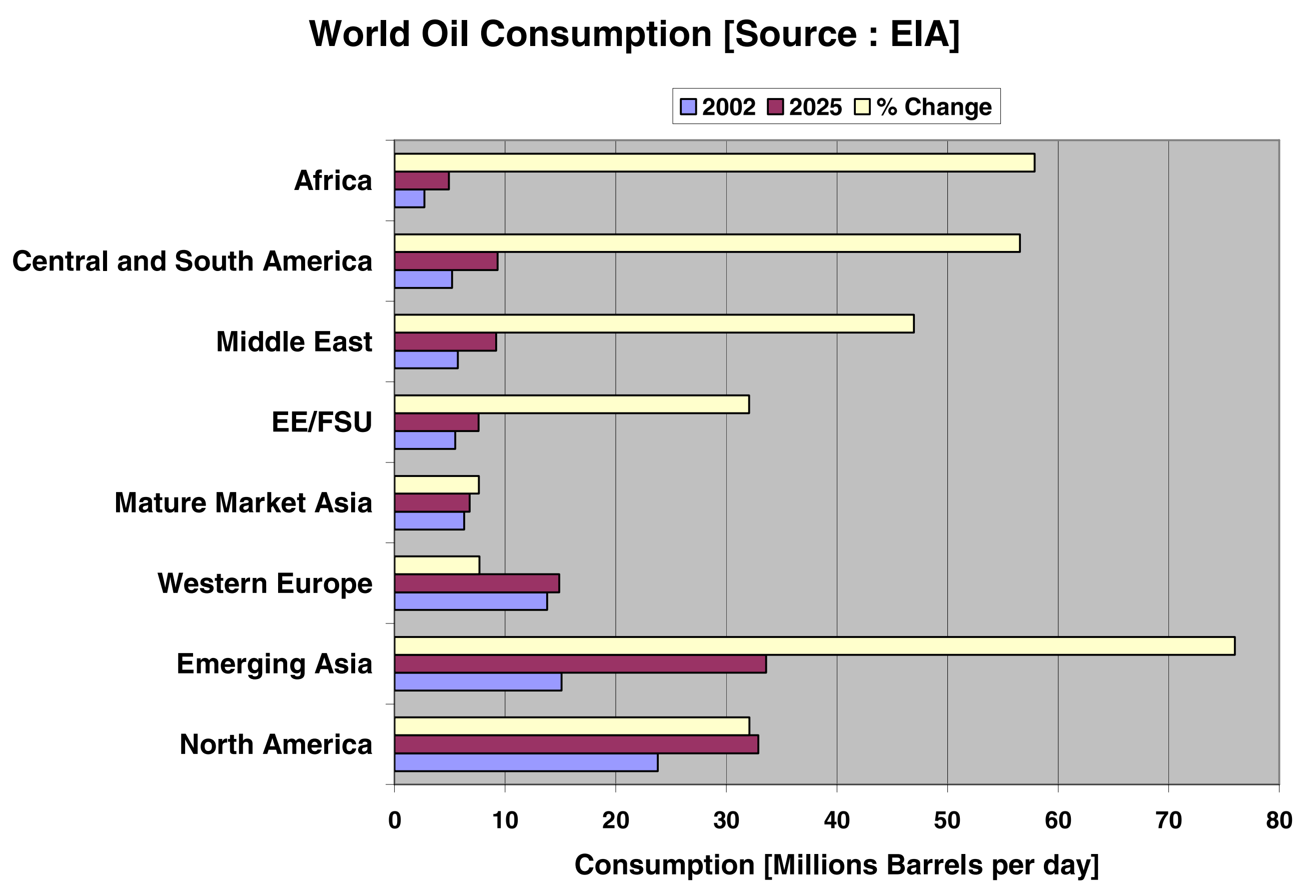
Oil and gas production, demand and investment

http://www.exxonmobil.com/corporate/Newsroom/Publications/eTrendsSite/chapter1.asp



National Aeronautics and Space Administration

World Oil Consumption by Regions for year 2002 and projection for year 2025 with percent increase in consumption.



www.nasa.gov

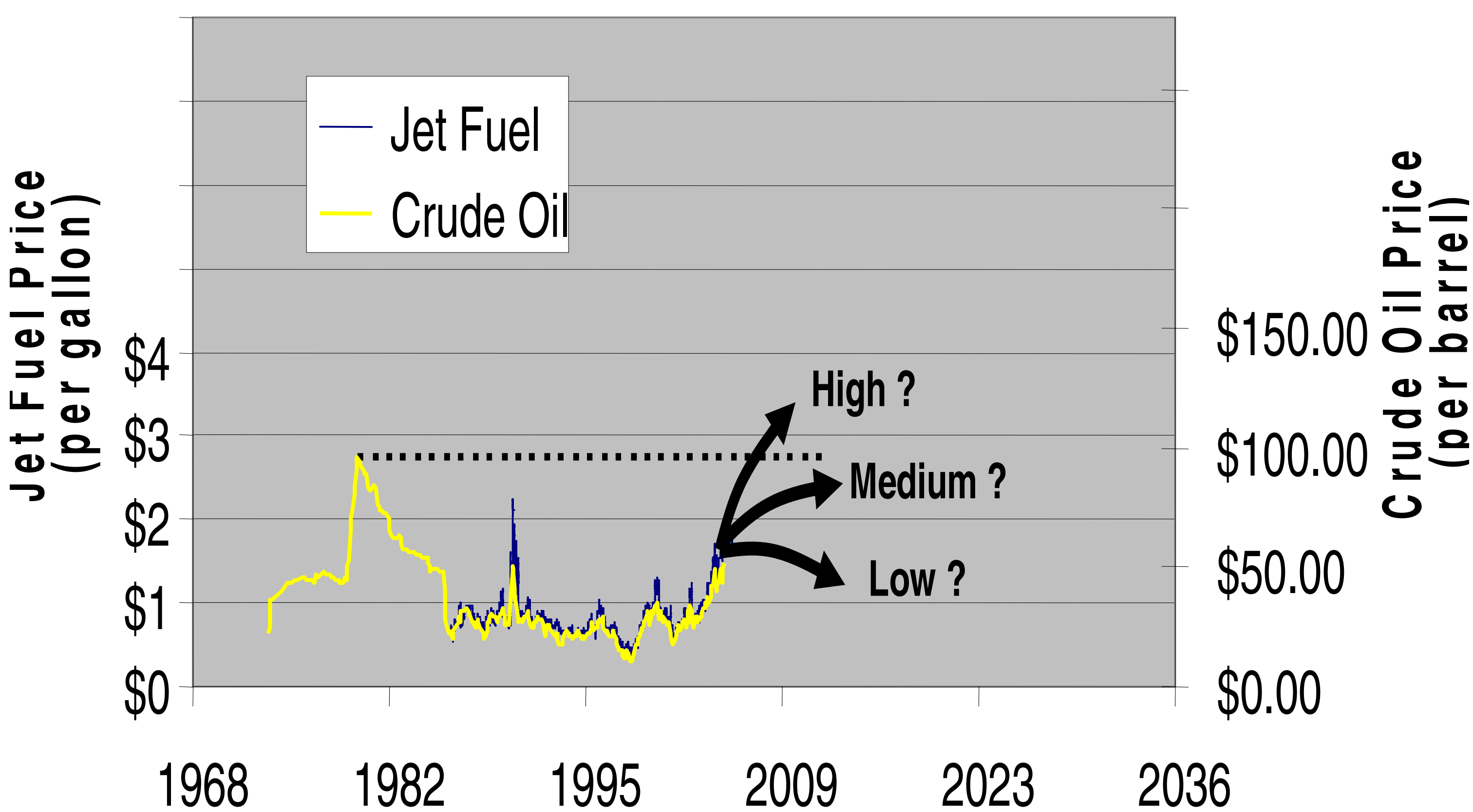
Fuel Price Scenarios

- The cost of fuel and availability becomes the major concern. For aviation this fuel is Jet A.
- The price of Jet A closely follows the price of crude oil and we are looking to the price in year 2020.
- The low-price ($1.33/gal) represents a linear extrapolation of fuel and crude oil prices for over a decade; current price highs will settle back down
- The medium-price ($2.67/gal) is a linear extrapolation over the past 5 years and nearly double the low-price.
- The high-price is a linear extrapolation over the past 3 years, ($ 5.12/gal) extending the trend in supply and demand and nearly four times the low-price. Not unreasonable as European petrol is $5/gal and some places diesel is $7/gal.
- This means that fuel costs will rise from about ¼ to ½ the cost of operating the aircraft.

National Aeronautics and Space Administration

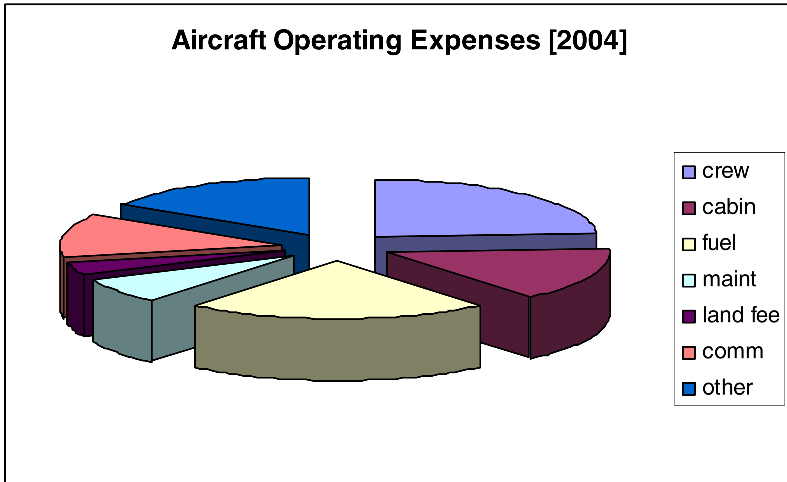
Comparison of historical price of crude oil to Jet-A fuel with possible future projections to the year 2020.

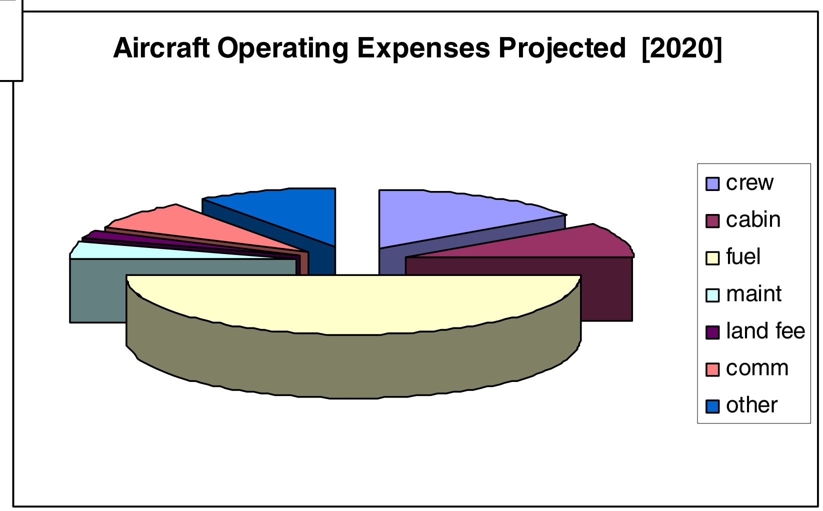
low $1.33/gal : **medium** $2.67/gal : **high** $5.51/gal



www.nasa.gov

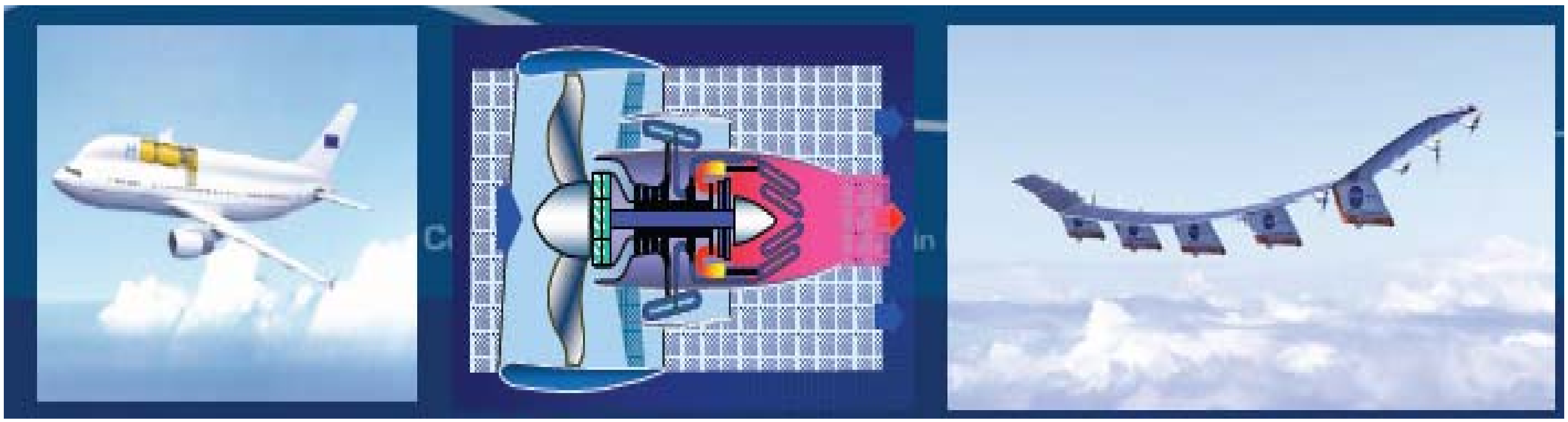
Aircraft Operating Expenses





National Aeronautics and Space Administration

Visions of future aircraft and engine configurations
[Szodruch (2005) and Broichhausen (2005)].



Hydrogen

Intercooler/Recuperator

Solar/Fuel Cells

Lower

&

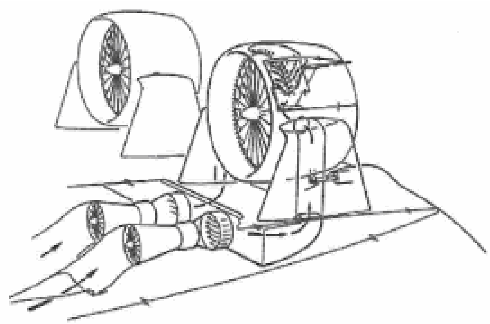
Slower

www.nasa.gov

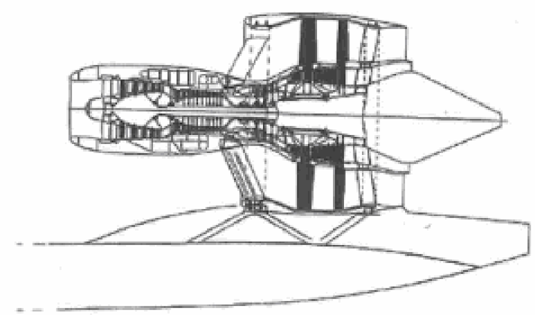
Potential Industrial Response

- So how will the aviation and transportation community in general respond.
- Systems integration designs from the well-head to disposal (cradle to grave). Engines and aircraft will be blended, green, efficient and integrated.
- Looking ahead to hydrogen which we feel will be the fuel of the future, yet appears more distant than first perceived. Gas to Liquid Fuel (GTL) as from natural gas (NG), coal or bio-mass appears to be an intermediate solution. Bio mass will help and is projected to produce 5 B-gal/year, but we use some 180Bgal of fuel per year(13.6Bgal 2004-domestic aviation only). Yet as with all new fuels, these fuels along with their additive packages, reactions both in energy release and materials life must be assessed. These can be very challenging problems yet very good opportunities for the seals and secondary flow community.
- Intercooling and recuperating in engines to increase overall energy utilization; Synergistic heat engine, fuel-cell electric and geared fan system
- Use renewable energy sources as solar, wind and more efficient energy conversion methods such as fuel cells
- Flights may become lower and slower with larger engine fans or turboprops
- Embedded engines may drive external fans or aft-mounted fans may be used particularly for blended wing body (BWB) aircraft

2005 vision of future aircraft configurations The Environmental Challenge, Bringing Technology to Market [Smith (2005)]



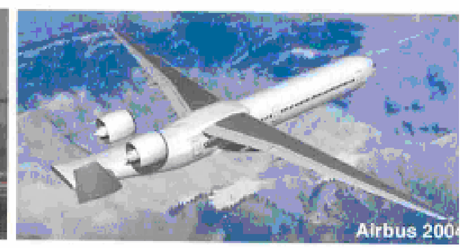
Embedded engine core with remote fan system



Aft fan concept

Silent Aircraft Initiative (Design SAX03)

Blended Wing Body concept



Pro-active green aircraft concept

Fuel Consumption and Global Warming Issues

- **A few sobering comments about Global Warming and green house gases (GHG : CO_2, CH_4, N_2O, SO_4, H_2*) are warranted. GHG-atmospheric lifetime: CO_2 (5-200yr); CH_4 (12-160 yr); N_2O (>100yr)**
- **Vast deposits of gas hydrates (methane) encompass the Americas and Japan but harvesting is quite complex and expensive**
- **Even if we could tap into gas hydrates (methane) and make GTL liquid fuels, we cannot continue pumping GHG - CO_2 into the atmosphere unabated. [Industrial revolution starts around 1760 - England (red arrow)**

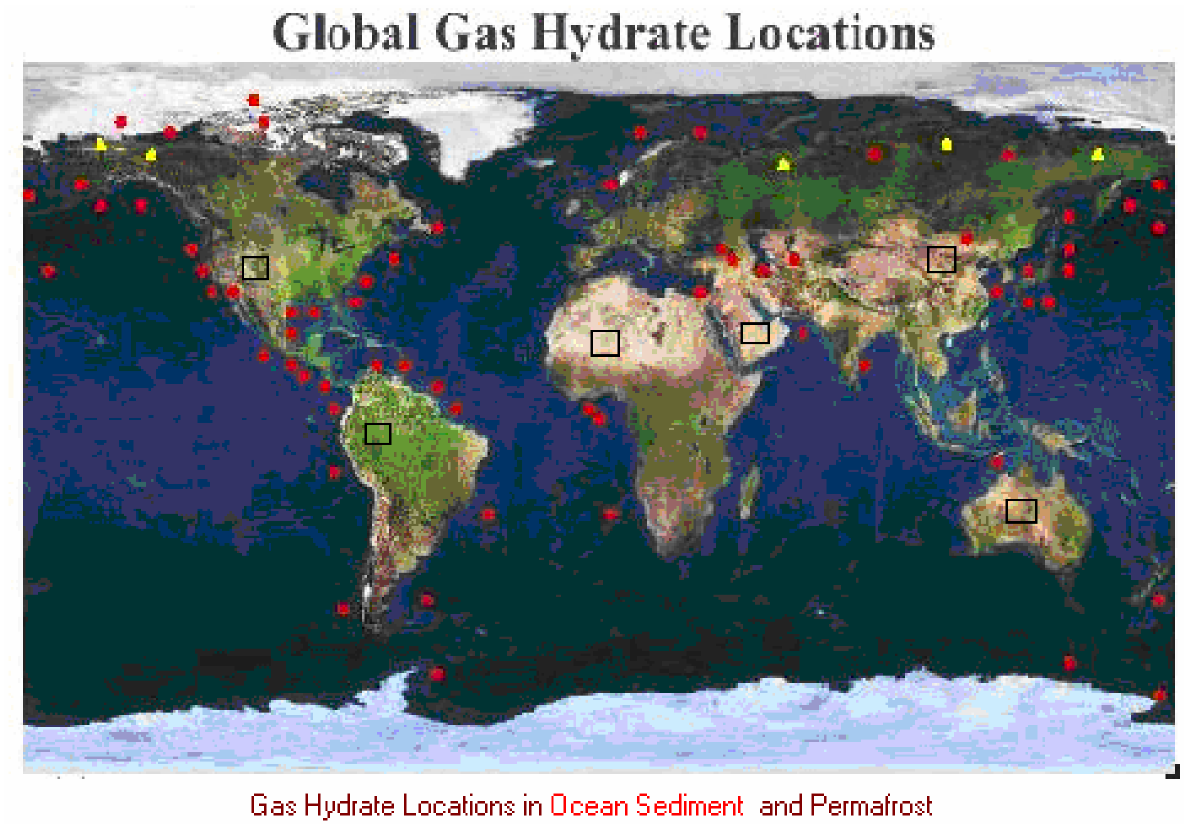
  Oil Rush - Titusville PA, Drake Oil Well 1859 (blue or yellow arrow)]
- **Small changes in ocean temperatures spawn large changes in planetary response. Hansen Global Warming & anthropogenic global warming**
- **Ocean sequestered Methane Gas Hydrates are approaching thermal stability limits.**
- **Uncontrolled release of methane from ocean gas hydrates exacerbates global warming.**
- **Methane traps over 20 times more heat per molecule than carbon dioxide.**
- **For those who know hydrogen, it is environmentally benign, easy to work with and forgiving as long as you respect and obey its power and authority; but when violated, it can unleash fury like hell never knew.**
- **(Added) Hansen Global Warming Model & anthropogenic global warming**
- Currently, and for the near term, most of the hydrogen produced will be by steam reformation of natural gas (methane) (or coal). *Upper atmosphere H_2 can grab O and prevents O_2 from becoming O_3; H_2-air engines produce NO_x

National Aeronautics and Space Administration

Red dots : Global distribution of gas hydrates
Open boxes : Smally's likely areas for massive solar power generation [20 TWe]

http://www.netl.doe.gov/scngo/NaturalGas/hydrates/databank/HydLocations.htm

Smalley http://www.sciscoop.com/story/2004/11/3/20322/6497

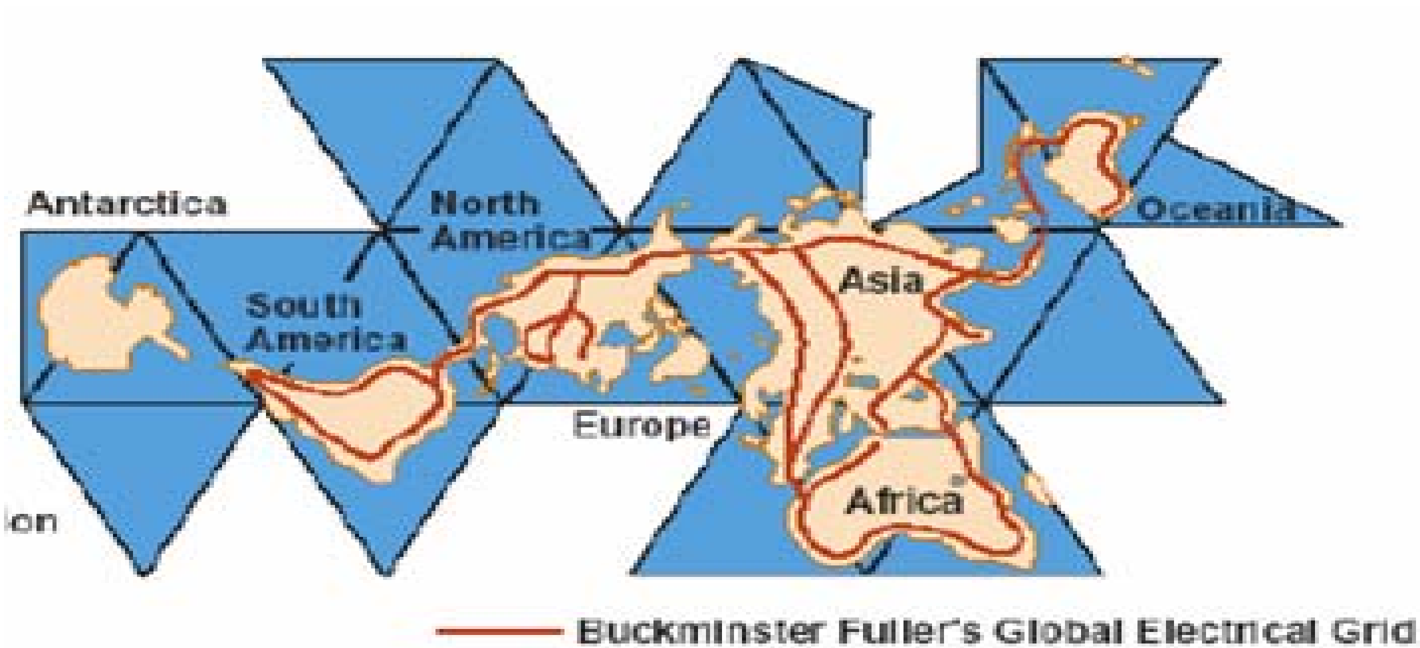


www.nasa.gov

The Fuller game of planet Earth global electrical grid

http://www.bfi.org/ and Hoffert, http://gcep.stanford.edu/events/workshops_solar_10_04.html

It is interesting that Fuller's energy lines tend to follow some lines of early human migration



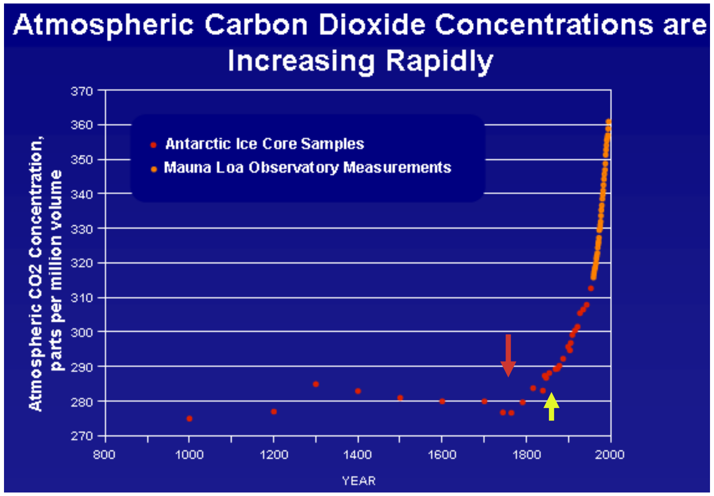
Anthropogenic Greenhouse Gases (GHG's) Concentrations, Rates and Atmospheric Lifetimes [http://www.grida.no/climate/ipcc_tar/wg1/016.htm]

Table 1: *Examples of greenhouse gases that are affected by human activities. [Based upon Chapter 3 and Table 4.1]*

	CO_2 (Carbon Dioxide)	CH_4 (Methane)	N_2O (Nitrous Oxide)	CFC-11 (Chlorofluoro-carbon-11)	HFC-23 (Hydrofluoro-carbon-23)	CF_4 (Perfluoro-methane)
Pre-industrial concentration	about 280 ppm	about 700 ppb	about 270 ppb	zero	zero	40 ppt
Concentration in 1998	365 ppm	1745 ppb	314 ppb	268 ppt	14 ppt	80 ppt
Rate of concentration change [b]	1.5 ppm/yr [a]	7.0 ppb/yr [a]	0.8 ppb/yr	-1.4 ppt/yr	0.55 ppt/yr	1 ppt/yr
Atmospheric lifetime	5 to 200 yr [c]	12 yr [d]	114 yr [d]	45 yr	260 yr	>50,000 yr

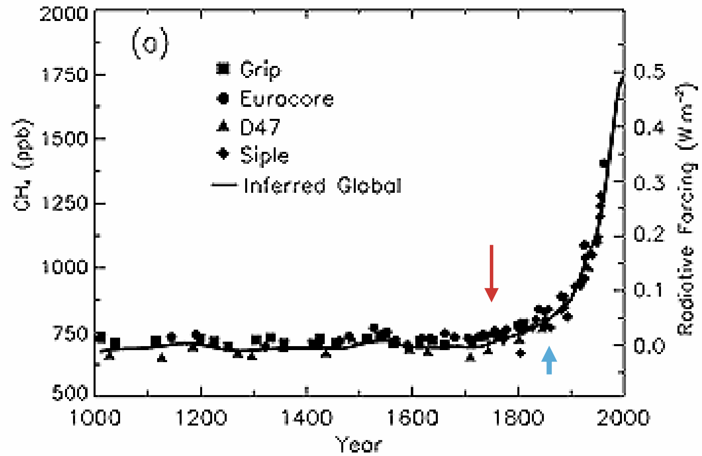
[a] Rate has fluctuated between 0.9 ppm/yr and 2.8 ppm/yr for CO_2 and between 0 and 13 ppb/yr for CH_4 over the period 1990 to 1999.
[b] Rate is calculated over the period 1990 to 1999.
[c] No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.
[d] This lifetime has been defined as an "adjustment time" that takes into account the indirect effect of the gas on its own residence time.

National Aeronautics and Space Administration



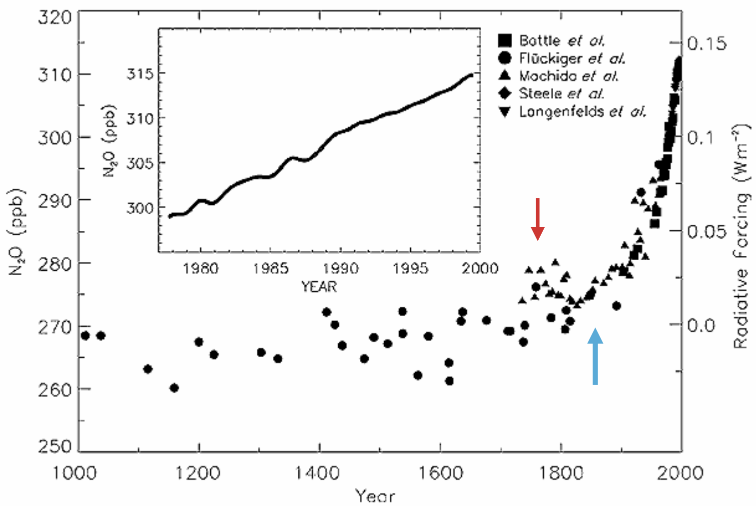
Methane Concentrations (ppBillion)

http://www.grida.no/climate/ipcc_tar/wg1/fig4-1.htm



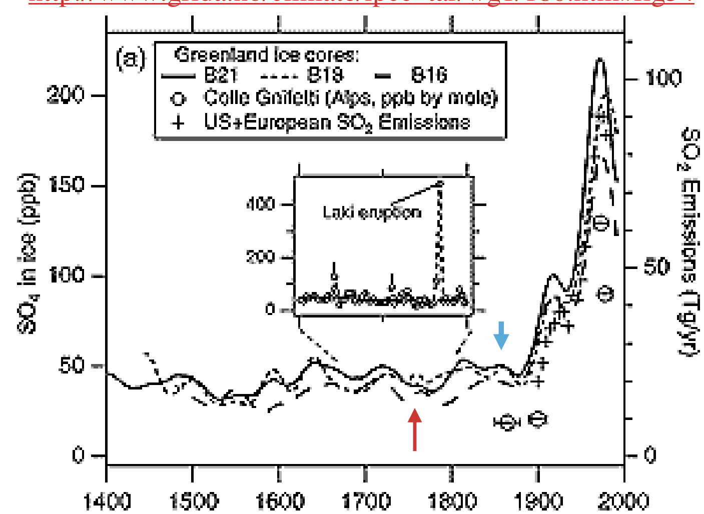
Nitrous Oxide Concentrations (ppBillion)

http://www.grida.no/climate/ipcc_tar/wg1/fig4-2.htm



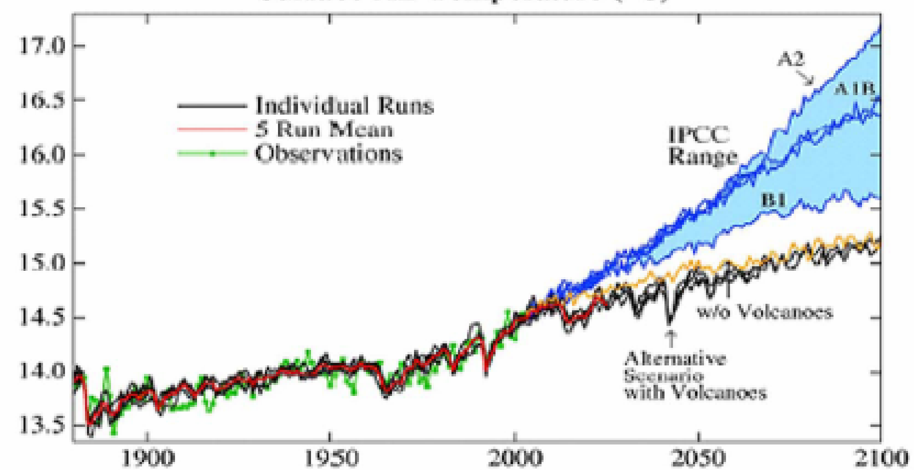
Sulphate Concentrations Peak ? (ppBillion)

http://www.grida.no/climate/ipcc_tar/wg1/180.htm#fig54



www.nasa.gov

21st Century Global Warming



Climate Simulations for IPCC 2007 Report

- ▸ **Climate Model Sensitivity ~ 2.7°C for 2xCO_2**
  (consistent with paleoclimate data & other models)
- ▸ **Simulations Consistent with 1880-2003 Observations**
  (key test = ocean heat storage)
- ▸ **Simulated Global Warming < 1°C in Alternative Scenario**

Conclusion: Warming < 1°C if additional forcing ~ 1.5 W/m^2 25

Source: Hansen et al., *to be submitted to J. Geophys. Res.*

Hansen, J.E., (2005) Is There Still Time to Avoid "Dangerous Anthropogenic Interference" with Global Climate? A Tribute to Charles David Keeling, Presentation at the American Geophysical Union, San Francisco, Dec. 6, 2005. http://www.columbia.edu/~jeh1/ [**Added after Presentation**]

Solar Wind Energies and New Energy Sources Need Development and Expansion

- Renewable energy sources are usually diffuse and require large facilities
- Biofuels work better, are more economical to produce for ground transportation, but sharply increase competition for food croplands.
- Noble laureate Richard Smalley (deceased-2005) conceptual 20 TWe power generation covers hundreds x hundreds of miles. Combined with Fuller's superconducting power grid system would enable renewable planetary energy.
- A solar-wind project in Australia will have a 7km diameter collector interfacing with a 1 km tower to extract 200 MW from wind turbines mounted at the base.
- GE Energy's 3.5MW Wind Turbine is large and placing this in perspective, it is as if one were rotating a Boeing 747-200; the blade diameter is that large.
- Wind turbines are rapidly gaining popularity in Europe and photovoltaic (PV) is expected to also expand rapidly.
- It becomes clear that we need (and still have time) to develop new sources of energy. Hf 178 bombarded by X-rays produces Gamma-rays for heating. The reaction stops when the X-rays stop; the half life is about 30 years and seems manageable vs 30 000 years. Water splitting needs to be perused as do ultra fast ultra intense laser applications in terms of fusion and new materials developments including new ways to strip and re-bind hydrogen into fuels. New methods and tools for development are being found in quantum mechanical applications to macro-systems and need to be developed into a set of new tool boxes for development of these new energy sources.

National Aeronautics and Space Administration

Solar - Wind turbines are BIG : A Perspective View

EnviroMission http://www.wentworth.nsw.gov.au/solartower/

Thresher (2004): http://gcep.stanford.edu/events/workshops_wind_04_04.html

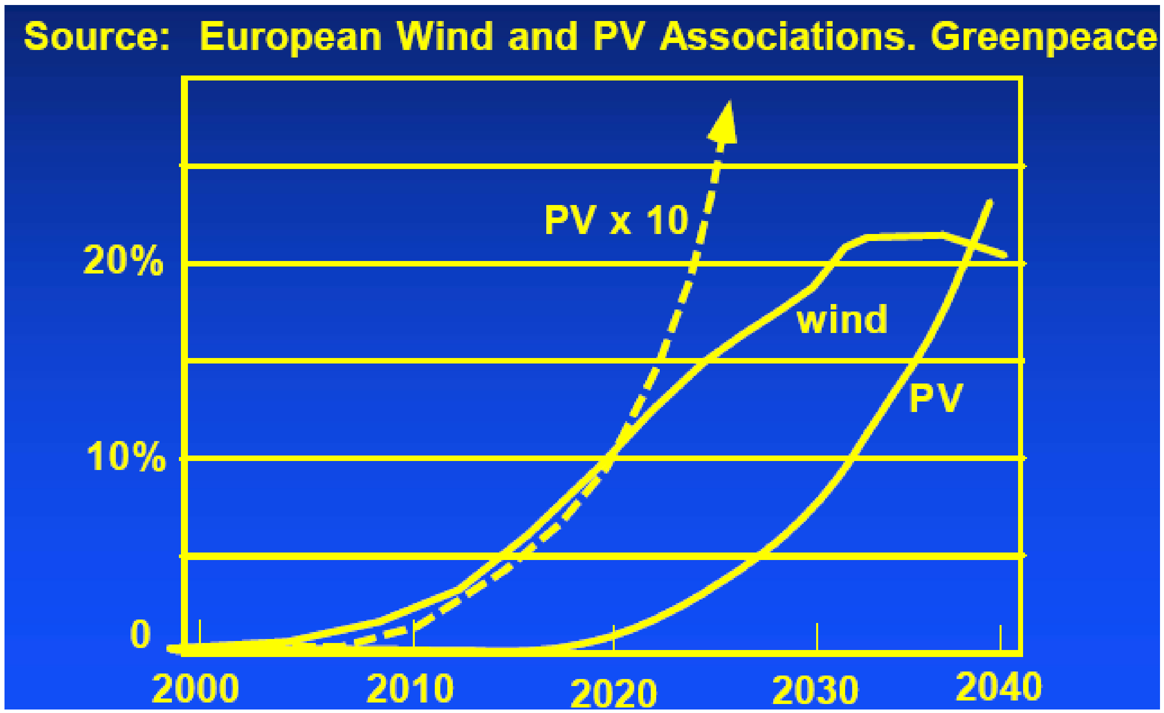
200MW Solar-Wind
7km collector ; 1 km tower

3.5MW GE Wind Turbine

www.nasa.gov

Potential Expansion of Solar and Wind Energy Sources

Green, M. (2004): http://gcep.stanford.edu/events/workshops_solar_10_04.html



SUMMARY

- Oil Limited

  Demand > Supply ; Reduce Dependency
- GTL fuels (NG ; coal ; bio) ; H2 future
- Promote, Develop Energy Efficient Integrated Engines and Vehicle Systems
- Develop solar-wind energy sources

  [reduce emissions, go CO2 neutral ; plant trees]
- R&D New Energy Sources

  {e.g., Hf178, Gas Hydrates, Ultra Fast Ultra Intense Laser Applications, water splitting ,Quantum-Macro …}
- ✓ Challenges and Opportunities Abound

References

- Daggett, David (2005) Water Injection Feasibility for Boeing 747 Aircraft, NASA CR 213656
- Broichhausen, Klaus (2005) Engine Technology Prepared in Europe: Innovation by Successful Partnerships, Paper ISABE-2005-1001, 17th International Symposium on Airbreathing Engines, September 4-9, 2005, Munich Germany.
- Smith, Colin (2005) The Environmental Challenge, Bringing Technology to Marker, ISABE-2005-1008.
- http://www.eia.doe.gov/oiaf/ieo/world.html ; http://www.eia.doe.gov/oiaf/ieo/oil.html
- http://www.exxonmobil.com/corporate/Newsroom/Publications/eTrendsSite/chapter1.asp
- “Oil and Gas Liquids, 2004 Scenario,” Chart produced by Colin J. Campbell, accessed July 2005 from http://www.peakoil.net/uhdsg/Default.htm
- “Oil and Liquids Capacity to Outstrip Demand until At Least 2010: New CERA Report” Press Release on June 21, 2005 from http://www.cera.com.
- Annual Energy Outlook 2005, accessed from July, 2005 from http://www.eia.doe.gov/oiaf/aeo/download.html
- http://www.eia.doe.gov/oiaf/ieo/oil.html
- “Boone Pickens warns of petroleum production peak” Author unknown. Written May 3, 2005, accessed July 2005 from http://www.peakoil.net/BoonPickens.html.
- Szodruch, Joachim (2005) [DLR, Germany] Technological Targets for Future Air Transportation in Europe, ISABE-2005-Pannel Discussion 3
- Smith, Colin (2005) The Environmental Challenge, Bringing Technology to Marker, ISABE-2005-1008.
- Swenson http://www.ecotopia.com/ISES/2005/Terawatts.ppt#277,1,Can Solar Energy Replace Oil?
- Smalley http://www.sciscoop.com/story/2004/11/3/20322/6497
- http://www.wired.com/news/technology/0,1282,66694,00.html?tw=wn_story_related
- Hoffert, Marty (2004) Space Solar Power, GCEP Solar Energy Workshop, October 18-19, 2004. http://gcep.stanford.edu/events/workshops_solar_10_04.html
- Green, M. (2004) Solar Energy and Its Potential, GCEP Solar Energy Workshop, October 18-19, 2004. http://gcep.stanford.edu/events/workshops_solar_10_04.html
- Buckmeister Fuller http://www.bfi.org/
- http://www.wentworth.nsw.gov.au/solartower/
  Thresher (2004): http://gcep.stanford.edu/events/workshops_wind_04_04.html
- Nobel Laureate Wangari Maathai Maathai, The Woman Who Plants Peace, World Arc Nov/Dec 2005 pp6-15
- Hendricks, R.C., Steinetz, B.M., Zaretsky, E.V., Athavale, M.M., and Przekwas, A.J., “Reviewing Turbomachine Sealing and Secondary Flows Parts A, B, C,” *The 2nd International Symposium on Stability Control of Rotating Machinery, ISCORMA-2003*, Gdansk-Poland, Aug. 2003, pp. 40–91. (Unabridged versions **NASA/TM—2004-211991/PART1, PART2, PART3.)**