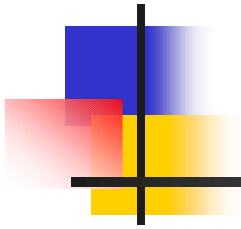


**Will fusion be welcome in the  
world of the mid 21st century ?**



Or will it be an Edsel ?

Ed Frieman  
APS Division of Plasma Physics  
Nov 14, 2002



## Why examine now ?

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- US actively exploring rejoining ITER
- Euratom, US & Japan post - ITER draft development plans under discussion
- Net electricity in 35 years, + 15 to full scale production, build on ITER; regional imperatives differ
- Sharp competitive assessments will likely follow tabled plans
- The transition to a sustainable world is emerging as the dominant vision of the future
- May likely be the umbrella for examining fusion's future role
- Seek conditions for positive positioning of fusion in the global context of the mid-century



## Some tools to probe these issues

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- Studies of critical global trends
- Scenarios of future world trajectories  
*think - draft world plans*
- Technical analyses of fusion vis-a-vis other technologies on a broad range of issues
- Analysis of tradeoff possibilities between energy, environment, economics and equity
- New partnerships and alliances
- Address specific criticisms
- Seek fusion applications with redeeming social value
- Provide feedback to development plans
- Maintain small agile cadre to follow zigs and zags



# What is sustainability anyhow ?

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- Integrates and balances economic, social and environmental issues in decision making
- ***to improve peoples lives, conserve our natural resources, and protect our environment in a world growing in population, with ever-increasing demands for food, water, shelter, energy, health services, sanitation and economic security***
- Rio Summit '92 provided conceptual framework, Agenda 21
- Followed by a decade of studies, analyses, hopes and rhetoric
- Johannesburg '02 attempted to set actions in place



# Sustainability today

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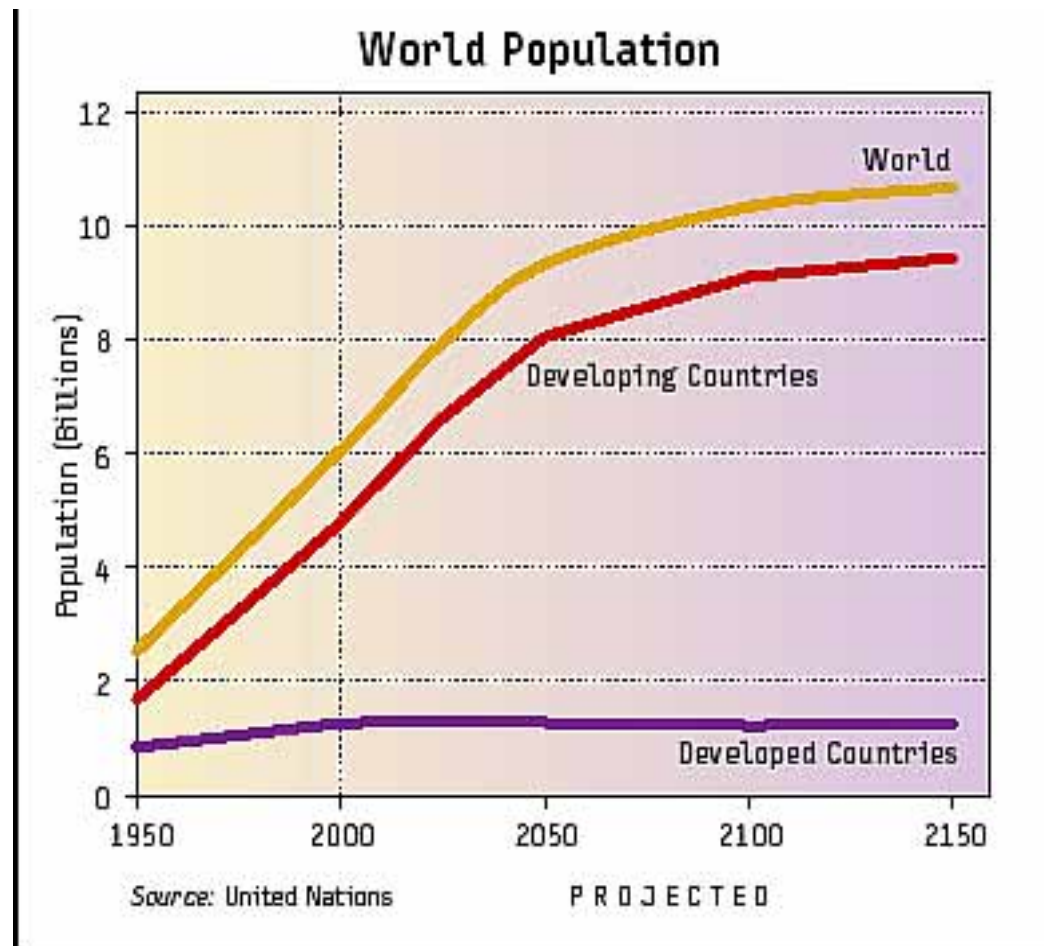
- Have learned that it is a dynamic concept
- New issues
  - focus on richness of cultural diversity
  - acceptance of globalization for developing world
  - events of Sept 11 reinforced need for development with harmony
- All global environmental considerations, including climate change, lie within the Sustainable Development Intergovernmental structure
- Business, especially multi-nationals, becoming heavily involved - WBCSD
- Business - NGO alliances beginning
- Sustainability now widely accepted as a guiding principle for public policy

# Critical trends

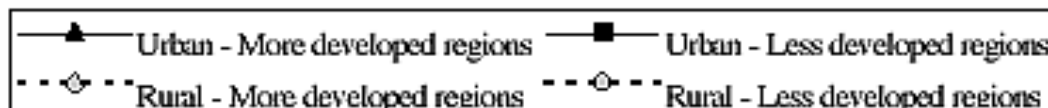
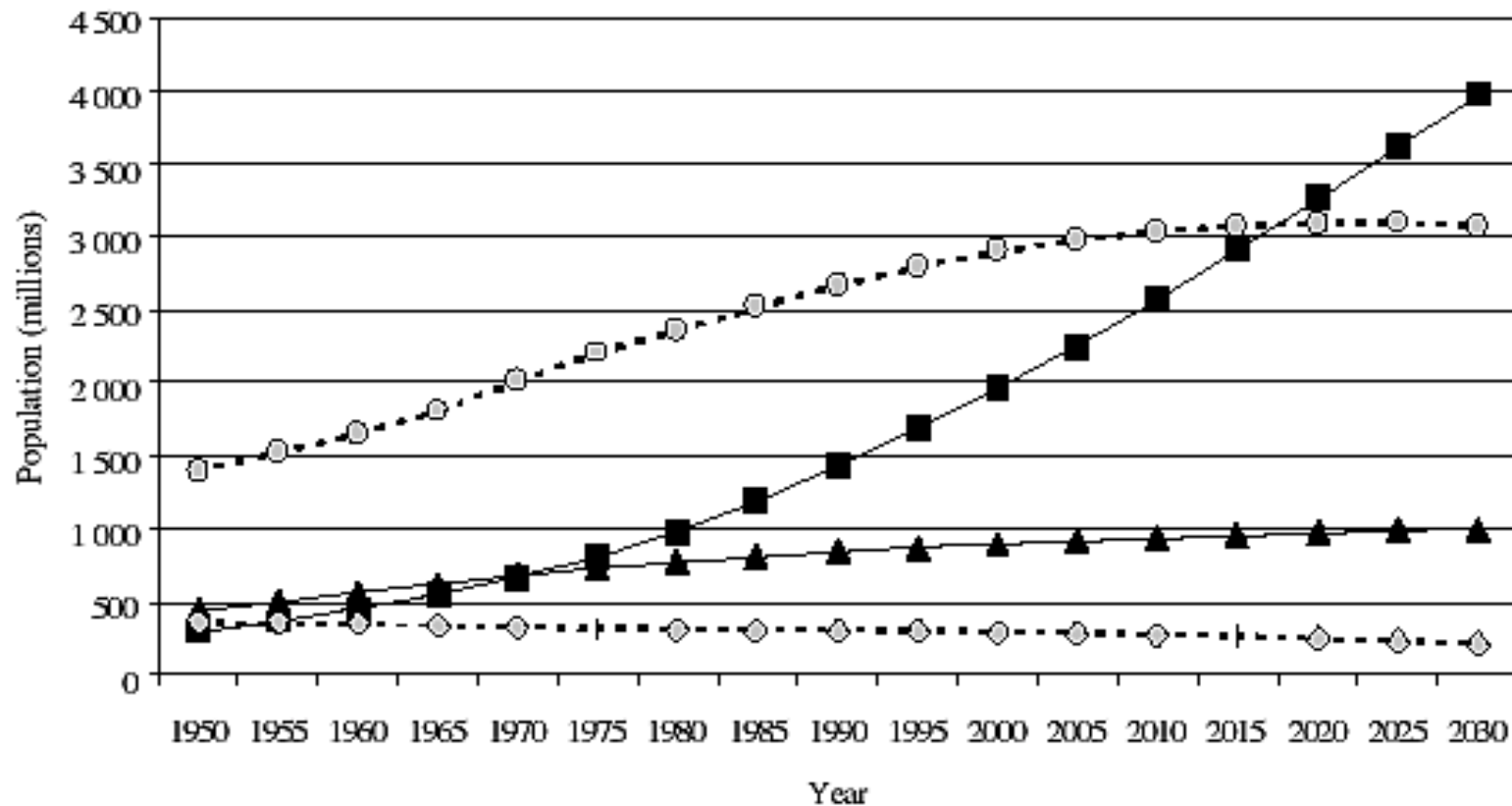


Source : UN WSSD

# World Population Projections

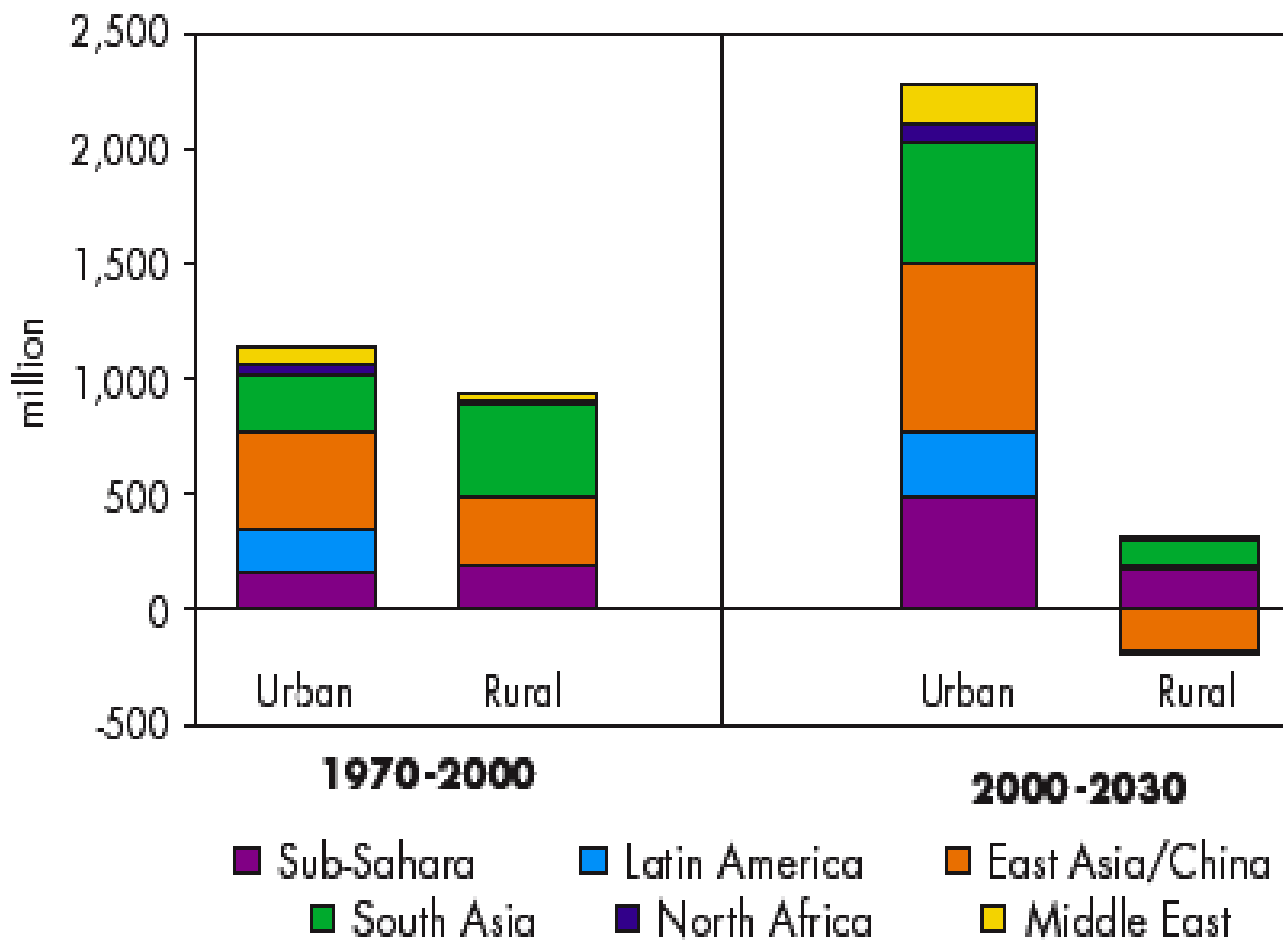


# Rural-Urban trends, 1950-2030





# Urban-Rural trends by region in developing world

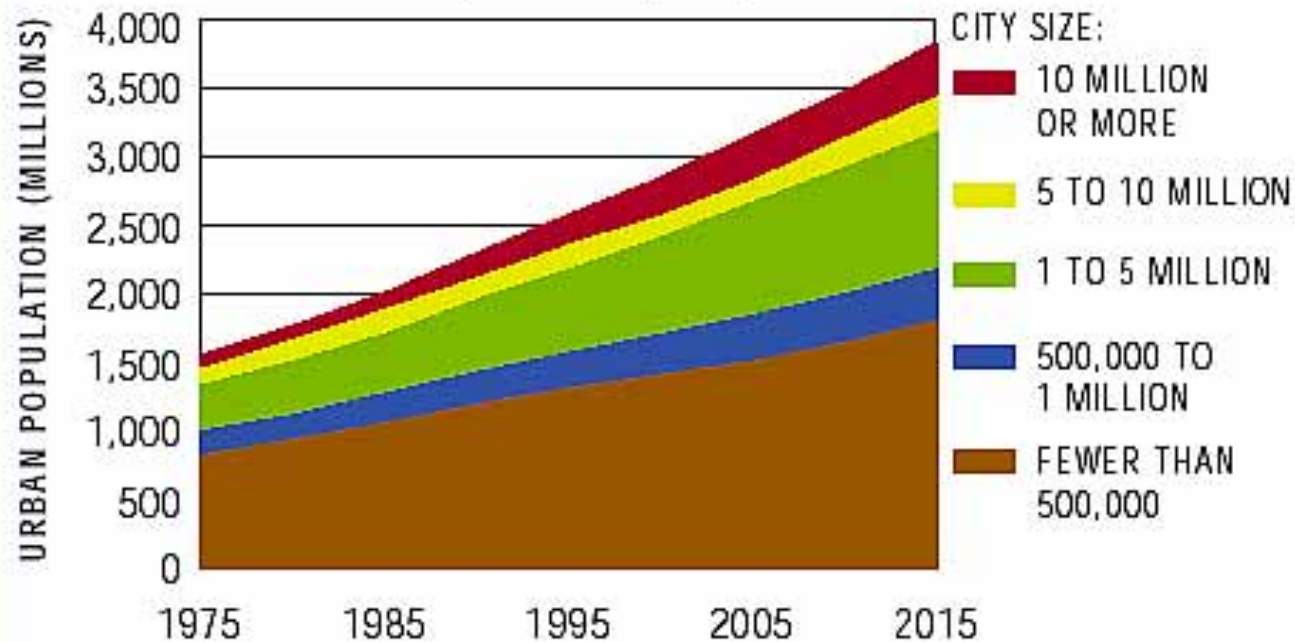


Source: UN Population Statistics for projections, World Bank and OECD for historical data.

# Distribution by city size

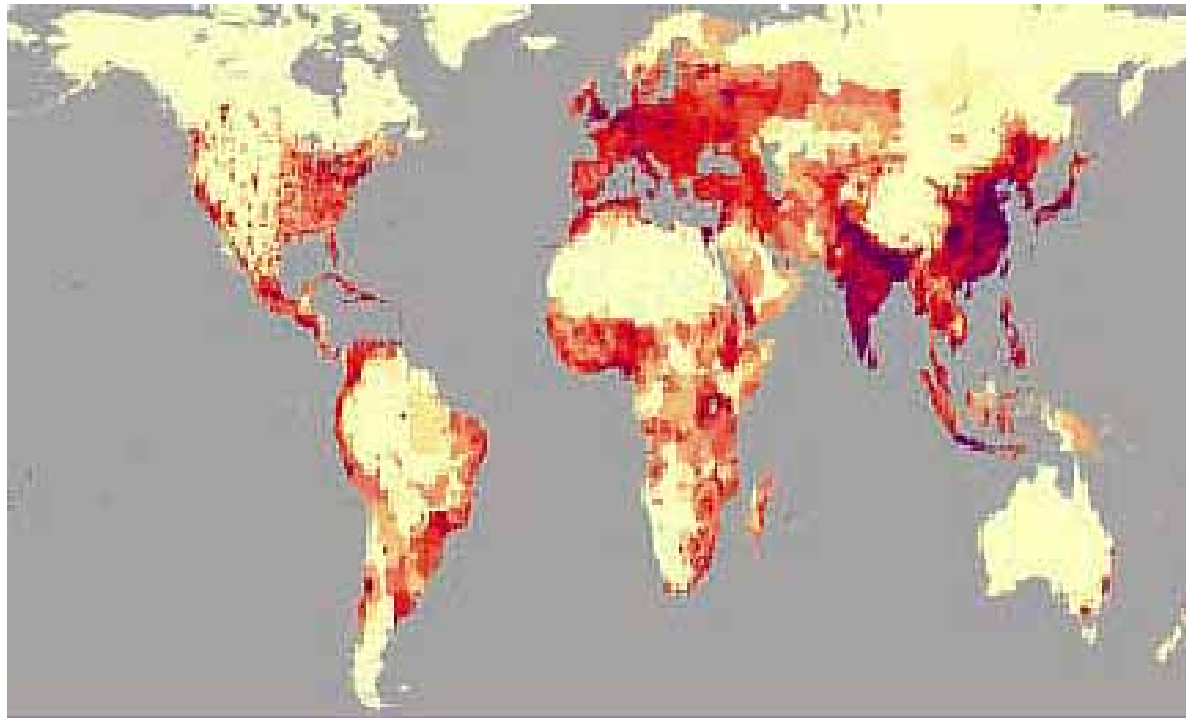
## Living In An Urban World

World Urban Population by City Size, 1975 -2015



SOURCE: UN Population Division, 1999.

# Where are they all ?



More than half the global population currently live in the coastal zone; this is expected to increase to 75% by 2025.

Source LOICZ



# Observations

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- Largest population growth expected in Asia
- Growth largest in cities with less than 500,000 population, not in “mega cities”
- 75% of world will live near coasts
- On these time scales, a major driver for the implementation of fusion is the developing world
- As population continues to cluster in coastal regions, off-peak power use for desalination may be an attractive option
- Developed world power markets not driven by population growth - urgency for fusion driven by other imperatives
- The developed world drivers are relatively well-understood, so focus here on developing world

# Critical trends



Source : UN

# Energy Resources

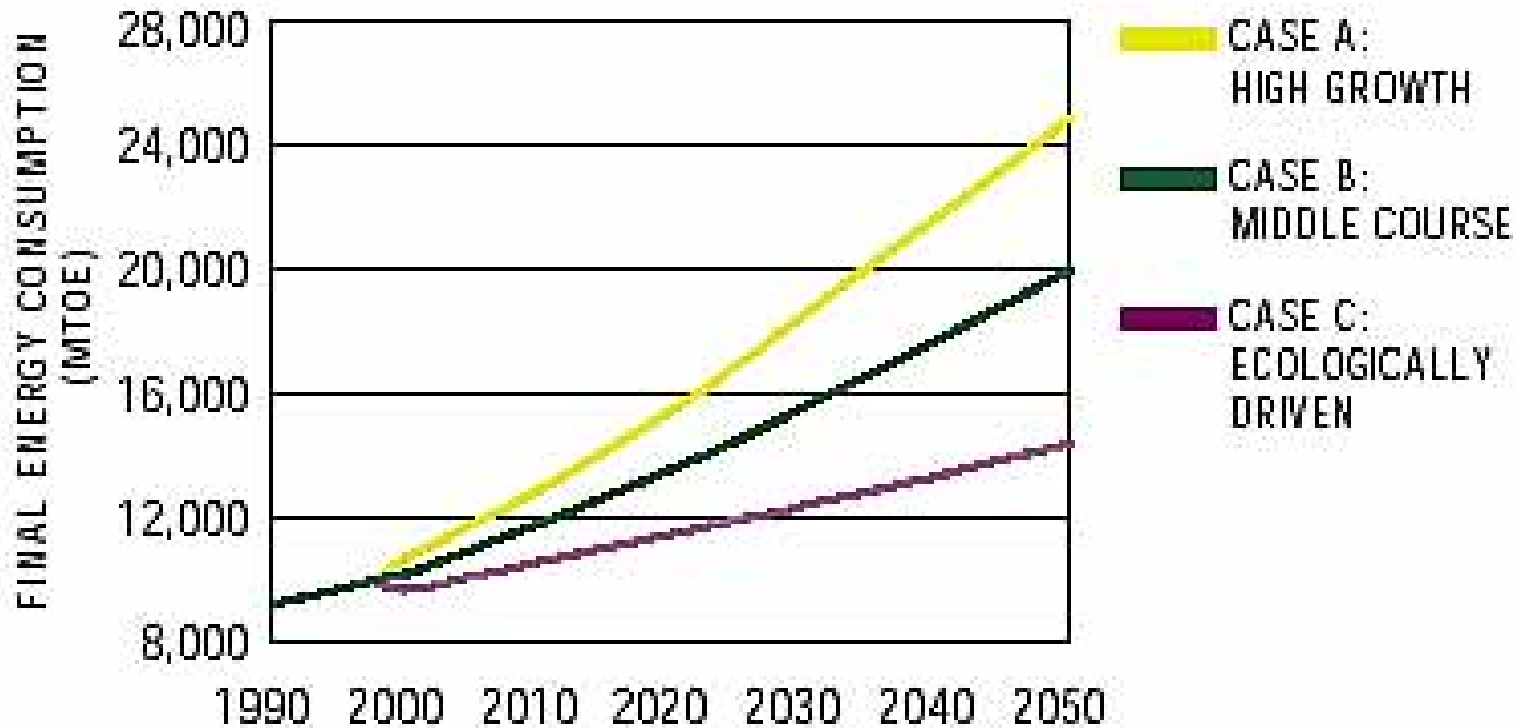
- World non-renewable resources -150,000 quads
- World Consumption- 380 quads in 2001

Resource	Reserves	Resources	Resource base <sup>d</sup>	Additional occurrences
Oil	11.11	21.91	32.42	45
Conventional	6.00	6.07	12.08	
Unconventional	5.11	15.24	20.35	45
Gas	14.63	34.93	49.81	830
Conventional	5.45	11.11	16.57	
Unconventional	9.42	23.91	33.24	830
Coal	20.67	179.00	199.67	
Fossil total	46.63	235.24	281.83	875
Uranium				
Open cycle in thermal reactors <sup>b</sup>	1.83	3.52	5.41	7.1 <sup>e</sup>
Closed cycle with fast reactors <sup>d</sup>	113	211	325	426 <sup>b</sup>
Fossil and fissile total <sup>e</sup>	48	446	575	1,400

Source WEA

# Energy consumption and sustainability

Three Scenarios of Global Energy Consumption Projected to 2050



SOURCE: IASA/WEC, 1998.



## The energy-poverty nexus

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- 1.6 billion people have no access to electricity  $\Rightarrow$  1.4 in 2030
- 2.4 billion rely on biomass  $\Rightarrow$  2.6 in 2030
- Electricity lack, biomass use are hallmarks of poverty precluding industrial activities, jobs, amenities
- UN suggested actions
  - √ access to energy services
  - √ energy efficiency
  - √ renewables
  - √ advanced fossil technologies
  - √ energy and transport
- Almost all scenarios assume essentially little future for fission
- Estimate \$ 500 billion / yr for 30 years to reach electricity sustainability
- World-wide energy subsidies now run \$600 billion / yr
- Return to biomass issue later





# Observations

Current electricity use  
per capita in kwh

North America	11,830
OECD	8,053
East Asia	824
South Asia	313
Sub-Saharan Africa	439
Middle East	1,186
China	687
Transition economies	2,788
Least developed countries <sup>a</sup>	83

- Question: will cities of 100,000 at 1/3 OECD level be 'overpowered' by plants at 1-1.5 GW ?
- If so, can make H<sub>2</sub>, H<sub>2</sub>O , heat, put on grid if city density warrants
- Suggests investigating feasibility of acceptable fusion plants smaller than 1 GW
- Adds emphasis to importance of research program in parallel with ITER to search for optimal reactor



## Global energy observations

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- World is not running out of energy, but it is running out of environment
- Current world trajectory is not sustainable
- The critical problem is steering a path to sustainability while supplying the developing world's needs
- The potential role of fusion in alleviating poverty is a powerful social good which needs to be explored
- All scenarios indicate that energy sustainability is attainable only by a mix of policies, plans, technologies, and funding
- Fusion has been absent from these considerations except for some negative comments and an occasional pat on the back
- Need to explore ways to get it on the energy agenda
- Suggest be part of discussion in post-ITER planning

# Critical trends

POPULATION.....

POVERTY AND INEQUALITY.....

FOOD AND AGRICULTURE.....

FRESHWATER.....

FORESTS.....

ENERGY.....

CLIMATE CHANGE.....

HEALTH AND WATER.....

HEALTH AND AIR POLLUTION.....

SOURCES AND FURTHER INFORMATION..

Source : UN



# Climate

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- Climate for climate change is changing
- Droughts, flooding, storms, monsoons, glacial retreat and many other phenomena present evidence of change now
- Developing nations vulnerability is shifting their attention to adaptation
- While they dominate emissions later in the decade, don't want to limit growth now
- Some Kyoto support waning as its shortcomings in timing and magnitude become understood, but general agreement will be signed within the year
- More complex mix of mitigation and adaptation options may follow
- Current arguments for presenting fusion as a zero CO<sub>2</sub> emitter may want to be augmented by viewing in a mitigation/adaptation context

## An emerging global environmental issue

- Dense cloud of pollution from fossil, biomass over South Asia
- reduces sunlight by 10-15%,
- Bangladesh, Nepal, Northeast India flooding
- Drought in Pakistan, Northwest India
- 100,000's of deaths reported
- transporting across world
- drives climate & air pollution
- fossil sequestration now must capture particulates as well as CO<sub>2</sub>
- Fusion immune to both





## Critical observations on fusion

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- World Energy Assessment - UNDP
- - **argument weak for extensive RD&D investment in large, sophisticated, ‘lumpy’ inflexible technologies such as fusion power.....”**
- WEA argument based on premise and promise of distributed generation, learning curves for lowering costs, local control, microturbines, solar etc
- Population projections however, show that **‘lumpiness’ is good for you**
- Distributed systems are not ‘lumpy’ enough



## more observations

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- Amory Lovins on fusion
- **“ Bad idea...not cheaper than uneconomic fission .. waste/ proliferation concerns...yet another costly complex centralized way to make electricity.. Already have a safe, free one appropriately cited 150 million km away ”**
- Cost, waste, proliferation issues have previously been addressed by DOE and the community in detailed studies
- Fusion not found wanting in these dimensions, but proliferation resistance might be revisited for reassurance in view of terrorism concerns
- ‘Complex’ may likely be true, but not necessarily a killer issue
- Centralized is just another way of saying ‘lumpy’



## Yet even more observations

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- Recent negative report by Hirsch circulating on Hill comparing fossil, fusion, photovoltaics
- Three scenarios: restrict air pollution, global warming constraints, high prices due to scarcity.
- Argues against fusion on cost, rad-waste issues, regulatory burden, complexity, need for p, B<sup>11</sup> ??
- Important issues already dealt with
- European Greens - lump fusion and fission in same basket on rad-waste issue
- New Scientist report of secret UK effort to kill fusion unfounded
- Williams - **if fusion..brought to commercial readiness in 50 years..market prospects.. stiffer competition than fission now**
- Based on competition with renewables & advanced fossil
- Fusion survives these criticisms but more competitive analyses needed



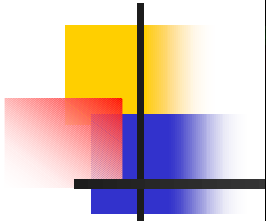
# Energy Security: A Key Requirement for Sustainable Development

## Perspective and Action Plan



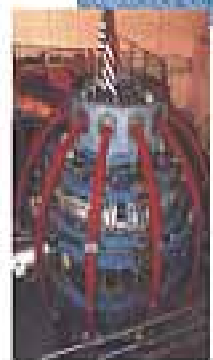
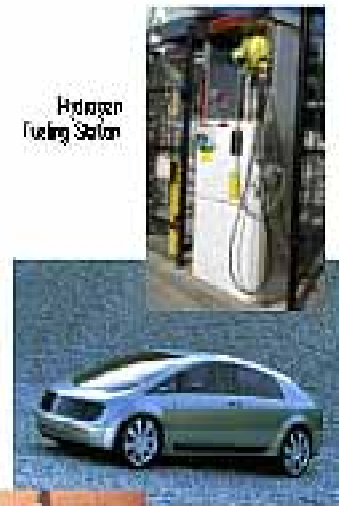
**Energy for Sustainable Development  
IEA/UNEP/Eskom**

- **Robert Card**
- **Under Secretary**
- **US Department of Energy**
- **August 30, 2002**



## US ENERGY ACTION PLAN Develop Long Term Options for Secure Sustainable Energy

- **Hydrogen**
  - Clean transportation fuel of the future
  - Produced from emissions-free nuclear, renewables, or emissions-trapped fossil
- **Fusion**
  - The US is one of the world's largest supporters of fusion research
  - Considering joining the ITER consortium
- **Emissions-trapped fossil**
  - Work with IEA
- **Generation IV nuclear**



# Potential alliance ?



Launched at WSSD Johannesburg

# Fusion is an Attractive Domestic Energy Source

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- **Abundant fuel, available to all nations**
  - Deuterium and lithium easily available for thousands of years
- **Environmental advantages**
  - No carbon emissions, short-lived radioactivity
- **Can't blow up, resistant to terrorist attack**
  - Less than 5 minutes of fuel in the chamber
- **Low risk of nuclear materials proliferation**
  - No fissile or fertile materials required
- **Compact relative to solar, wind and biomass**
  - Modest land usage
- **Not subject to daily, seasonal or regional weather variation**
  - No large-scale energy storage nor long-distance transmission
- **Can produce electricity and hydrogen**
  - Complements other nearer-term energy sources

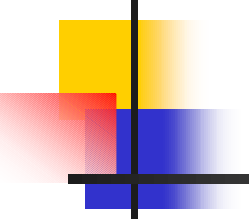
Stolen from Rob Goldston



# A grab bag of things

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- Water - serious problem
- Biodiversity , energy can help
- How many earths
- How many people
- How big is the footprint
- Dow-Jones sustainability index
- Global Reporting Initiative
- Indicators and the Environmental Sustainability Index
- Sam, GEF, World Bank, Robobank, CDM
- Tellus - Pole Star, design your own world
- I=PAT, Impact = Population x Affluence x Technology
- The “2%” solution

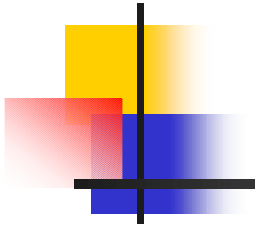


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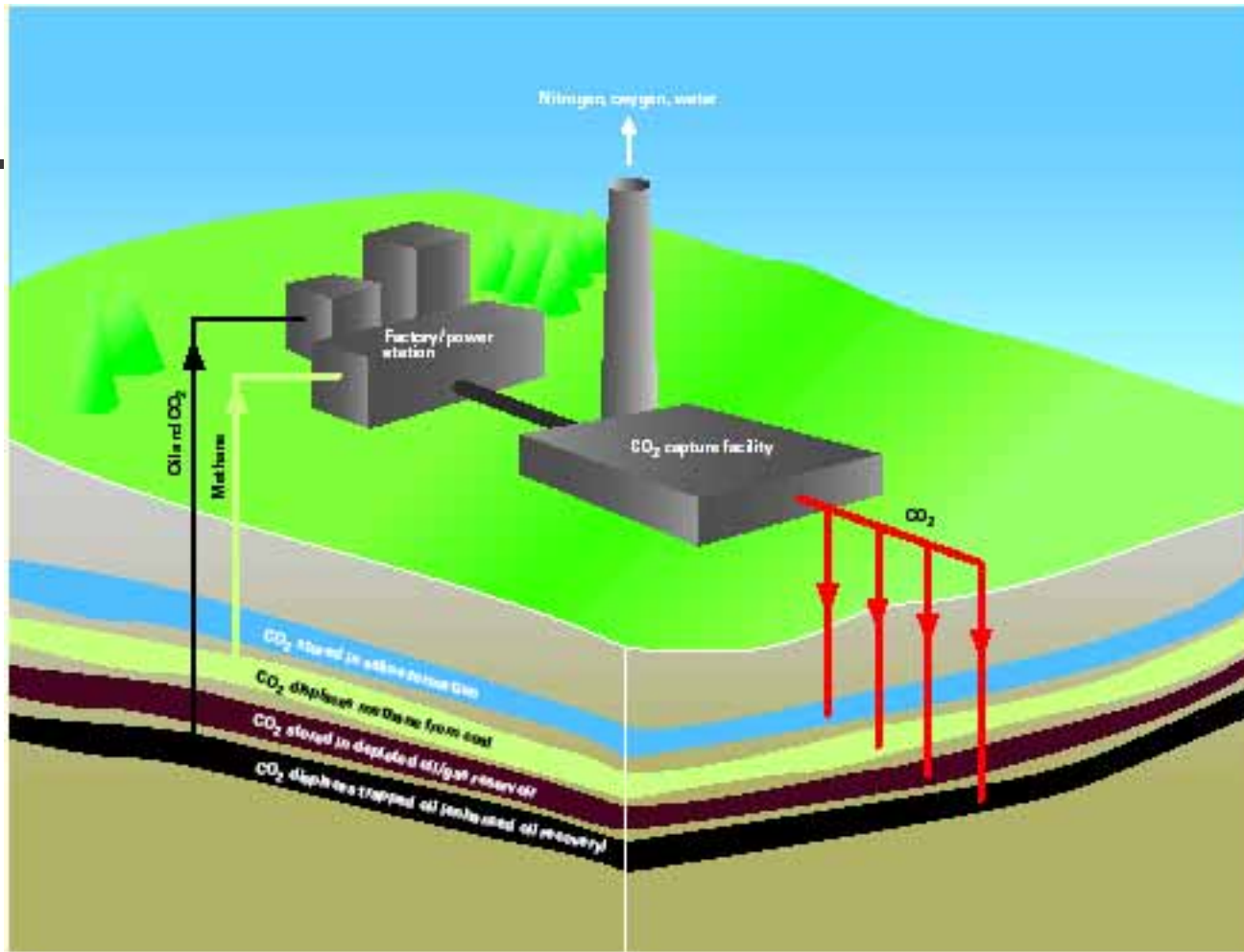
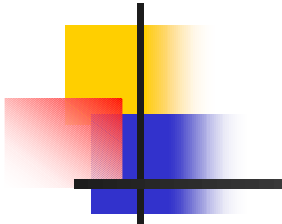
“Men and Nature must work hand in hand. The throwing out of balance of the resources of nature throws out of balance also the lives of men.”

Franklin D. Roosevelt

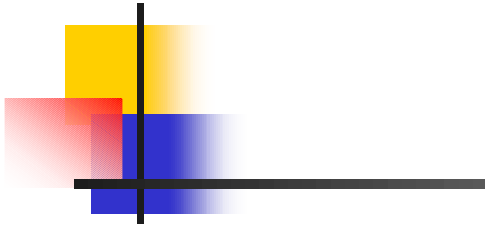
Perhaps we can show that fusion holds one of the important keys to a sustainable world



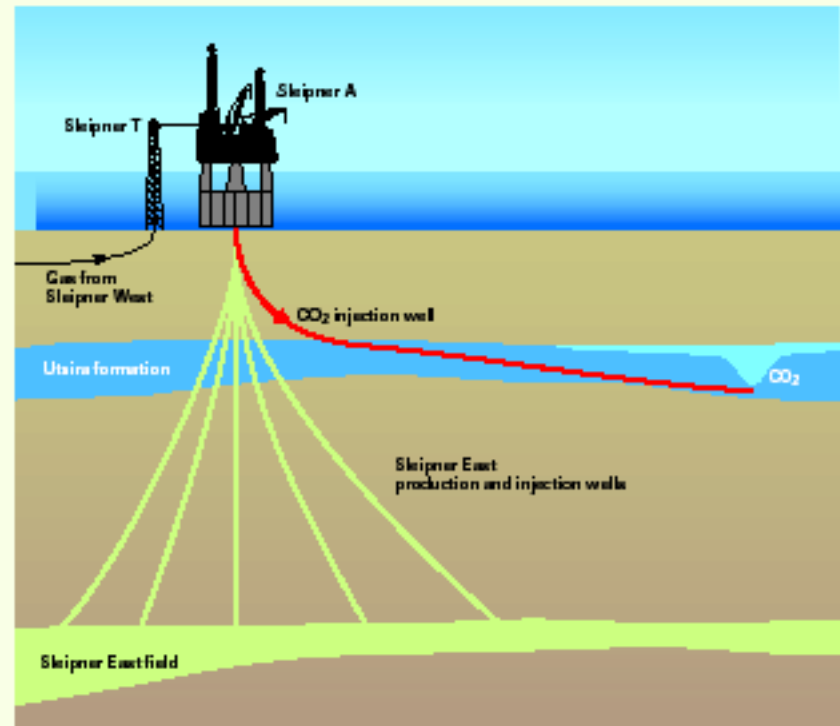
# Backup charts







## Saline aquifer storage of CO<sub>2</sub>



## Many routes to hydrogen vehicles

Boxed fuels are only one of several potential ways of delivering hydrogen to vehicles. Hydrogen can be produced by hydrocarbon reforming, nuclear or solar electrolysis and biomass conversion. Natural gas steam reforming is by far the cheapest currently, even if carbon dioxide sequestration is required. The most efficient and effective way of distributing the hydrogen is through the existing liquids and gas infrastructure, producing hydrogen at retail sites or on-board vehicles. The critical issue is how to store it. There are four options:

**Solid hydrogen**, if commercialised, would provide superior convenience, safety and – possibly – cost. Breakthroughs could come anytime but most observers suggest they are at least a decade away.

**Liquid hydrogen** has generally been rejected as impractical and uneconomic because of concerns about boil-off, filling and safety.

**Gaseous hydrogen** is already used for bus fleets and could fuel ultra-efficient cars with redesigned fuel tanks. Hydrogen could be produced at retail sites by natural gas reforming, supporting parallel developments in stationary markets. There are concerns over filling, convenience, safety and consumer interest.

**On board reforming** of hydrocarbon liquids is preferred by automakers because of fuelling and space considerations, despite losing most efficiency benefits over advanced internal combustion. Methanol is easier to reform than oil but there are concerns about toxicity and the need to build new infrastructure for a transition fuel. Oil is easier to distribute, but faces performance and cost challenges and would require a cleaner fuel.

Cost is unlikely to be the determining factor. The winner will be determined by the strength of consumer interest in fuel cell vehicles, weighed against the convenience of

# our world and climate change

## Electricity generation

The amount of energy used to generate electricity has doubled since 1970 and electricity demand continues to grow. Fossil fuels are used to generate most of this electricity. As a result, the electricity sector accounts for 20% of global carbon dioxide emissions from fossil fuels.

## Transportation

Vehicles account for around 20% of global carbon dioxide emissions from fossil fuel use. Cars are the biggest contributors to these carbon dioxide emissions. Actions to reduce greenhouse gas emissions from the transport sector can simultaneously alleviate other problems such as local air pollution.

## Industry

When industrial uses of electricity are included, industry is responsible for 47% of global carbon dioxide emissions. Countries differ in their existing and predicted industrial energy use. Developed countries' industrial emissions are expected to remain relatively constant, while in developing countries emissions will rise as their economies grow. The treatment of rubbish and other waste also results in emissions.

## Buildings

Buildings use electricity and fuel for heat, light and power. Measures to improve building design such as insulation and efficient lighting and appliances could significantly improve the energy efficiency of buildings. Disposal and treatment of domestic waste also produce methane and carbon dioxide emissions.

## Agriculture

Agriculture is responsible for about 20% of human-related greenhouse gas emissions, emitting about 50% of our methane and 70% of our nitrous oxide. Across the world, rice paddies and ruminant animals emit large quantities of methane. Fertiliser use increases nitrous oxide emissions.

## Forests

Forests and plants take carbon dioxide from the atmosphere and use it for photosynthesis. They also release carbon dioxide through respiration and decomposition. The extent of emissions resulting from deforestation is uncertain, but it is estimated that between 600 million and 2.6 billion tonnes of carbon are released every year, much as 60-90 billion tonnes of carbon could be absorbed and stored over the next 100 years, if measures were taken to conserve and plant forests.

