

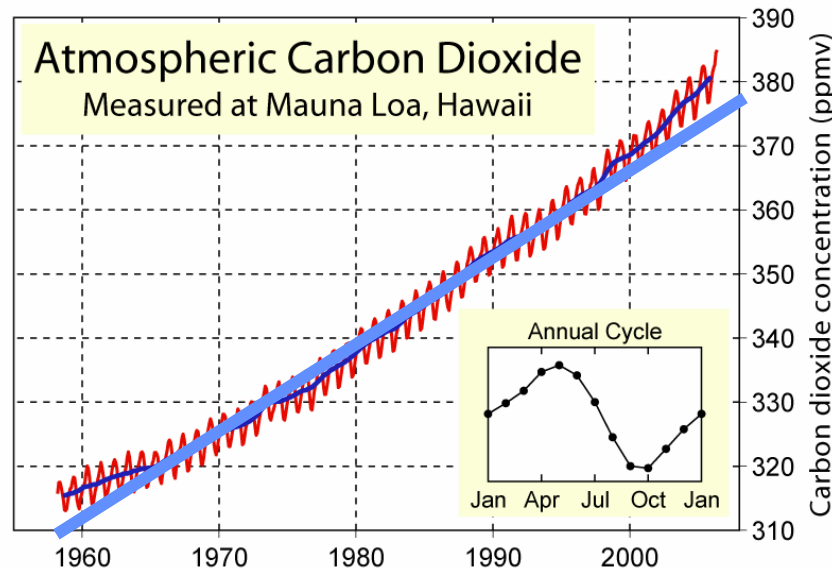
Promoting India's Development: energy security and climate security are convergent goals

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Outline

- Vision 2032 (End of 15th Five Year Plan)
- Pressing Questions
- Growth in Power generation:
 - Coal-fired
 - Natural Gas, LNG
 - Hydro
 - Nuclear
- Meeting Transportation Fuel needs
- India's Challenges: energy security, climate change, environment
- Policy Options – global win-win and technically feasible suggestions
 - Power generation
 - Transportation
 - Unconventional
- Global Energy Observatory – a web based tool for global energy systems
- Conclusions

Energy-environment-development-climate challenge requires evolving to

- Cheap
 - Copious
 - & Clean
- } Energy

Needs and impacts are global

6.7 (→10) billion people want same opportunities.
Balance demand, technology, policy, impact options

Development:	Short Term
Energy Efficiency:	Immediate
Environmental Impacts:	Medium Term
Climate Impacts:	Long Term

Vision 2032 is Cloudy: Anticipate many changes

2032: End of 15th Five Year
Plan

- Technology
- Regulations, Policies and international Treaties
- Resource constraints
- Globalization and Geo-politics
- Markets, Investment and Capital
- Pressure from civil society, environmentalists
- Land rights and access rights

- US is finally a player – both in policy and investment in R&D.
- Real \$ in alternatives to large central facilities for the first time.
- Technology is evolving fast on a number of fronts.

Vision of End-state

- **Midterm (2032): Fossil fuels as backup**
- **Long-term (2050+): Carbon-neutral**

India: Anticipated State in 2032

	2008 Capacity (Generation/Use)	2008 Fuel Used (CO2 Emissions)	2008 Fuel Reserves	2032 Estimated Capacity (Generation/Use)	2032 Fuel Required and Emissions
Population	1.12 billion (1.6% increase per year)			1.33 billion (Need 800 GW at 80% PLF → 0.5kW per capita)	
Coal-fired	100 GW (600 TWh)	0.5 Giga Tonnes (0.6 GT)	30-60 Giga T	300 GW (2000 TWh)	1.5 Giga Tonnes (~2.5 GT CO2)
Gas-fired	15 GW (50 TWh)	15 Bcm (0.04 GT)	1090 B cum	100 GW (300 TWh)	75 Bcm (~0.2 GT)
Hydroelectric	37 GW (123 TWh)			80 GW (~35% PLF) (200-275 TWh)	
Nuclear	4.12 GW (11 TWh)			30 - ? GW (40 GW) (300 TWh)	
Natural Gas	30.6/41.4 Bcm	(0.1 GT)	1090 Bcm	72 Bcm	~0.2 GT
Oil	0.77/2.9 MBpd	(0.5 Giga T)	0.8 Giga T	6 MBpd	~1 GT
CO ₂ Emissions (Giga Tonnes)		~1.2 Giga T			~4 Giga T

cm = STP cubic meters
T = Tonnes
M/B= Million/Billion

10% growth rate => increase by a factor of 9 by 2032

GW = GigaWatt
TWh = TeraWatt
hours
Bpd = Barrels per day

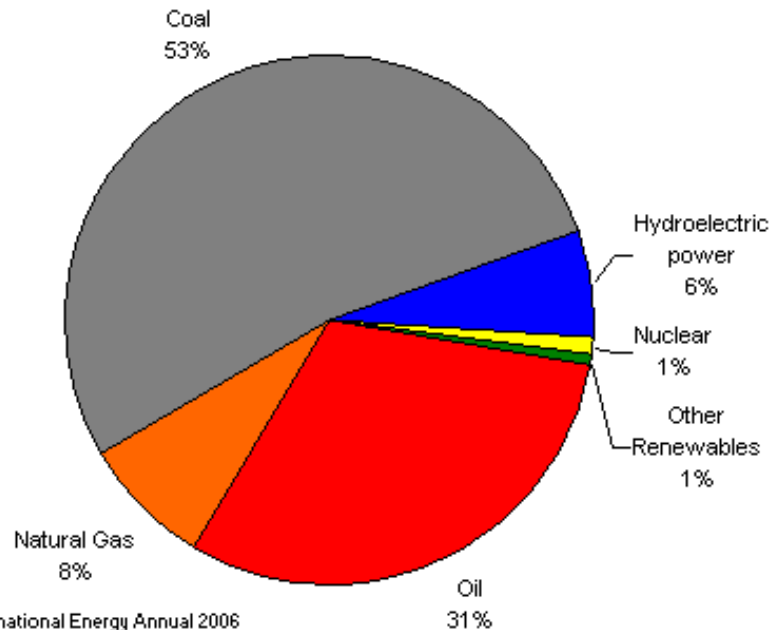
Questions

- How can India sustain a desired 10% growth?
 - Even a very optimistic energy scenario gets India from 800 TWh → 2500 TWh (**need ~ 6000 TWh @0.5kW/p**)
 - Changing balance between service, infrastructure, manufacturing sectors in future growth
- How will India offset the ~4 Giga tonnes CO₂ emissions from the power & transport sector?
- How will India reduce environmental impacts?
- How should India address the growing dependence on imported oil, U, natural gas and coal?

Need to examine resource constraints in a globalized world driven by Geopolitics

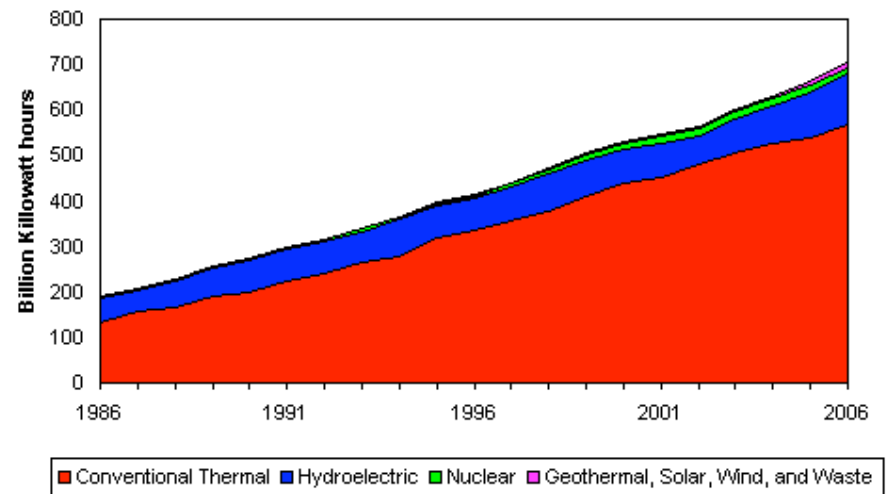
Power Generation

Total Energy Consumption in India, by Type (2006)

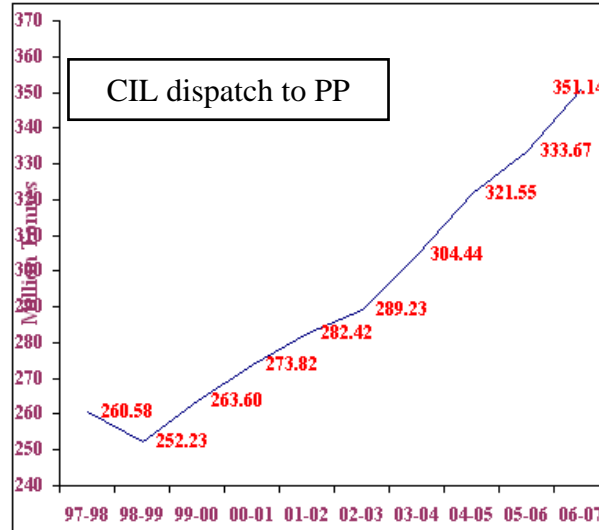
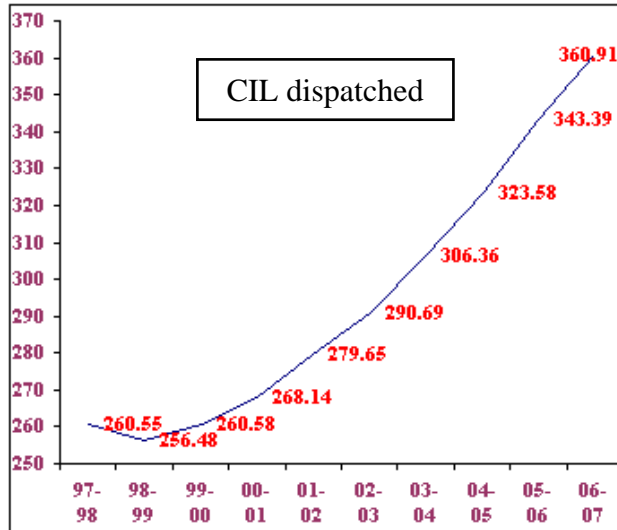


Source: EIA International Energy Annual 2006

Electricity Generation by Type, India
1986-2006



Coal and Coal-fired generation



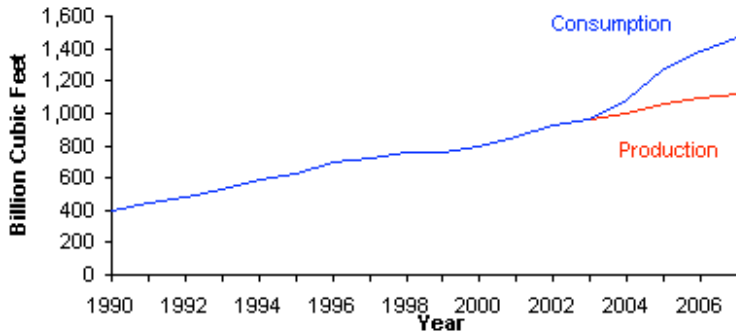
Country	Export MT	Reserves MT (BP)
Australia	260 (65%)	76200
Indonesia (x)	150	4328
China (x)	5	114500
South Africa	70 (28%)	30408
Russia	60 (18%)	157010
USA	50 (5%)	238308
Canada	30 (45%)	6578
Poland (x)	15	7502
Vietnam (x)	15	150
INDIA	Use = 512	58600

- Growth in Indian coal mining over last 5 years ~ **18 MT/year**
- 300 GW capacity at 85% PLF (~33% efficiency) needs ~ **1.5 GT** of Indian Coal
 - This requires growth @ 43 MT/year if only Indian Coal is used
 - And 2-3X growth in transport and delivery capacity
 - If growth @ 20 MT/year of Indian Coal → 400 MT of imported coal
 - Total Coal imported by India in 2008 ~30 MT (~20 MT was coking coal)
- Total global coal exported in 2007 ~ **800 MT** of which ~25% is coking coal.
 - Recent growth in world exported coal is @ 50 MT/year
 - Assume (i) carbon caps, (ii) exporting countries are assessed 50% of CO₂ generated:
 - Cost will rise and/or exporters will NOT invest in significant infrastructure development?

2008 Production: 600 TWh

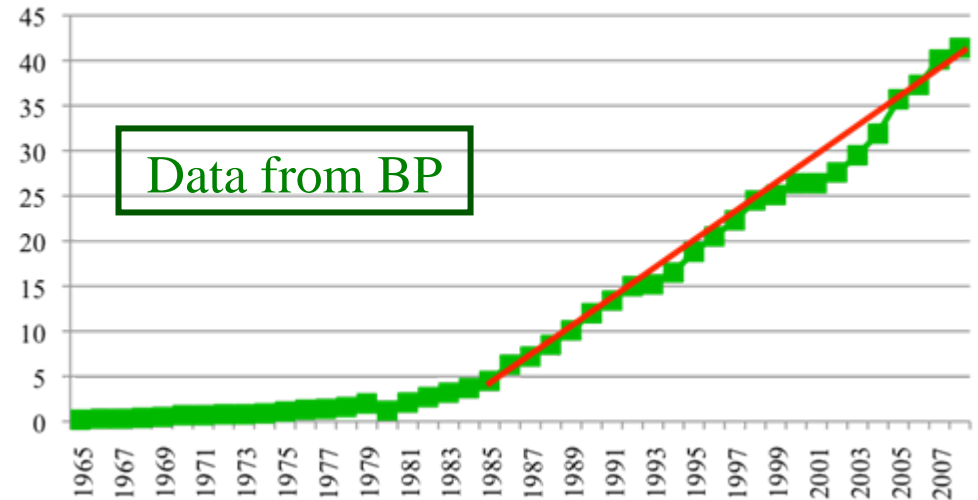
Natural Gas Consumption

India's Natural Gas Production and Consumption
1990-2007



Source: U.S. Energy Information Administration

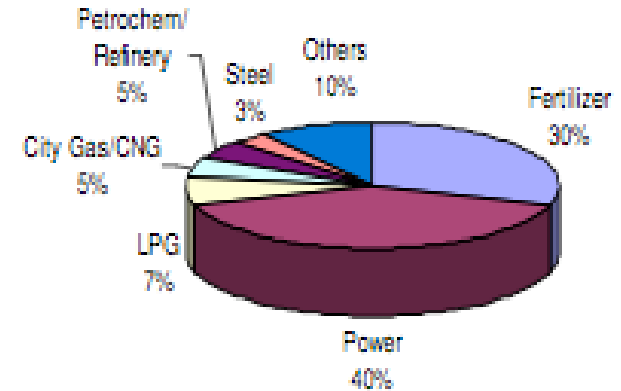
Natural Gas Consumption (B cum)



- Annual growth rate (since 1985) = 1.3 B cum/year
 - Extrapolating to 2032 → 72 B cum/yr = 200 Mcm/day
 - Current reserves of 1090 Bcm exhausted in 15 years
 - 200 MSCMD to the power sector = **350 TWh**

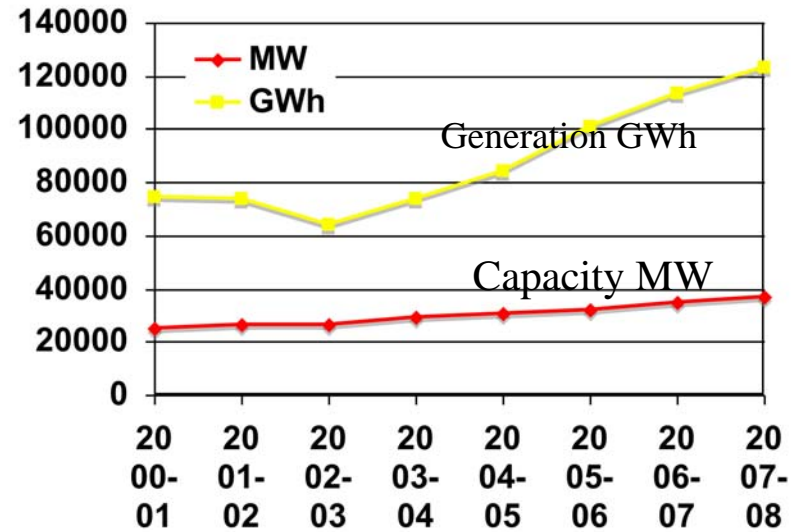
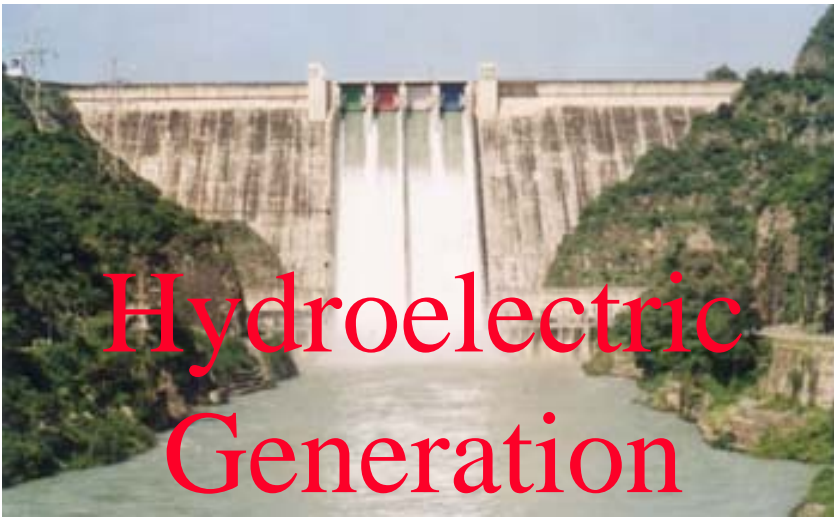
Natural Gas: Demand versus Supply

	Consumption MMSCMD	Shortage MMSCMD	Fuel Conversion/strand ed/closed assets	Greenfield Projects
Power	41	33	10	62
Fertilizer	28	13	24	16
Industry	9			
Petrochemicals /LPG/Captive	19	9		16
Transport	3			21
Sponge Iron	7	23		
Other	6			
Cumulative	113	191	225	340



Data from MoPNG

- KG production will boost domestic production → 160-200 MSCMD by 2012
 - KG gas will help current unmet demand but not Greenfield projects
 - Post 2020: Need 5-6 new mega field to sustain 200-300 MSCMD
 - Pipelines: ~100 MSCMD
 - LNG: ~100 MSCMD
- Possible unconventional (CBM) reserves ~800 BSCM. Need development
- Future (post 2032): Dependent on imports from Russia, Iran, Qatar, UAE



- 2008 Production: **125 TWh**
- Best load factor since 2000 is ~38%
- Growth in installed capacity is ~2 GW/year
- Doubling capacity 40→80 GW can provide between **200–275 TWh**
- Is hydropower best used for base load or peaking power or as storage (backup for wind, solar, interruptions in conventional)?
- What will be the impact of climate change on water resources?

Nuclear Power

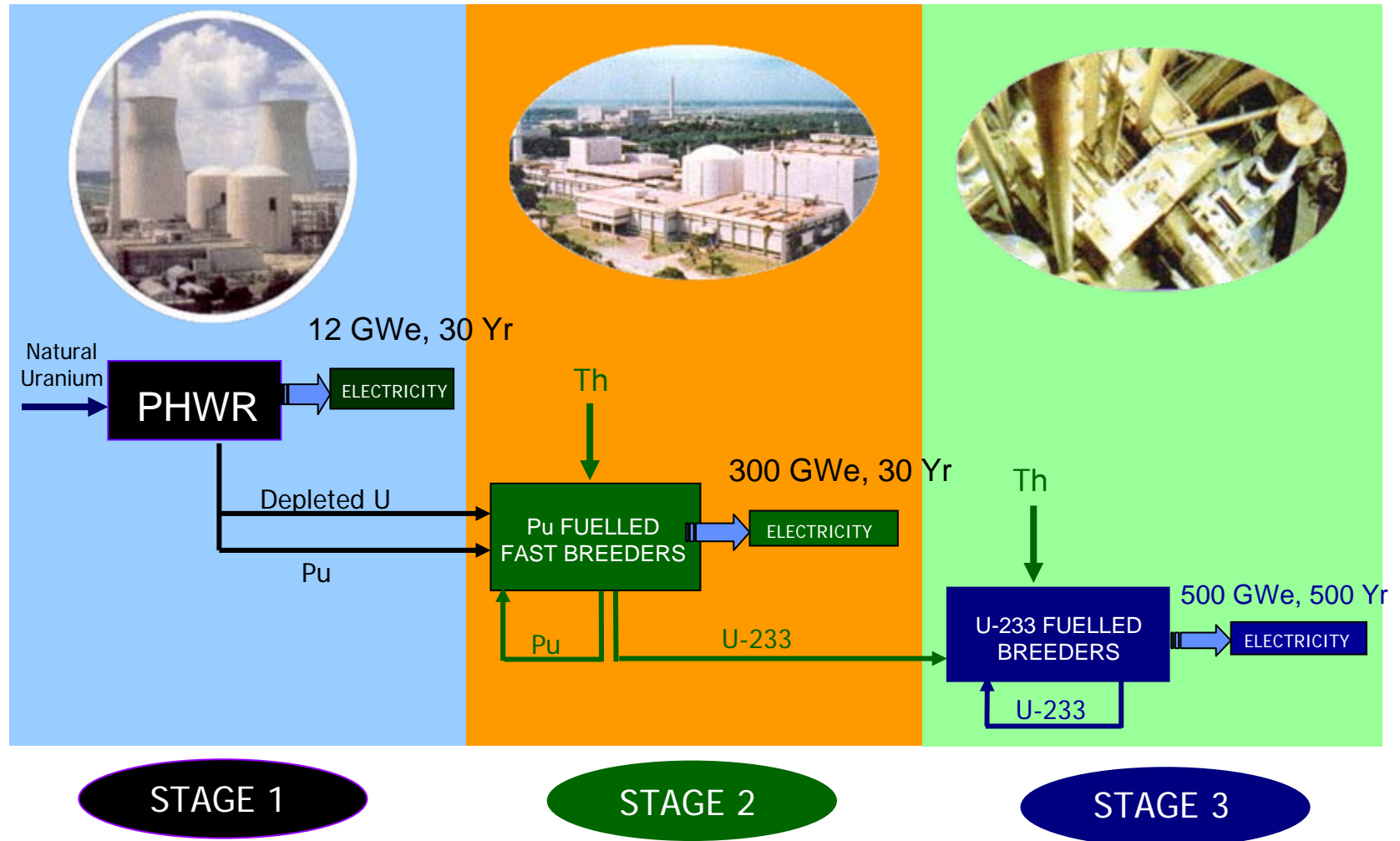
- Current Installed Capacity 4.12 GW (→22 reactors 6.6 GW in 2009)
- Mining of U ~300 T/yr sustains ~ 3 GW capacity at 90% PLF.
- Reactors in the Pipeline: (each one custom built at site)
 - 4-8 reactors from Russia (VVR-1000 @ 0.95GW) (Kudankulam)
 - 6 EPR from Areva France
 - Prototype FBR (470MW at Kalpakkam expected on line in 2011)
- India is embarked on a very ambitious 1-2-3 plan of LWR, PHWR, FBR and Thorium based fast breeder reactors.
- **Will GoI continue to foster growth by assuming all financial risks?**
- **Globally**
- Development of modular reactors (standardized, sealed and factory [mass] produced) that can be sited close to load centers.
- Acceleration of development of other Gen IV reactors
- Plan fuel reprocessing for 1 TW of nuclear power

Until Thorium breeder reactors are developed and commercialized, India will be dependent on the nuclear suppliers group for fuel and reactors



2008 Production: 13.1 TWh

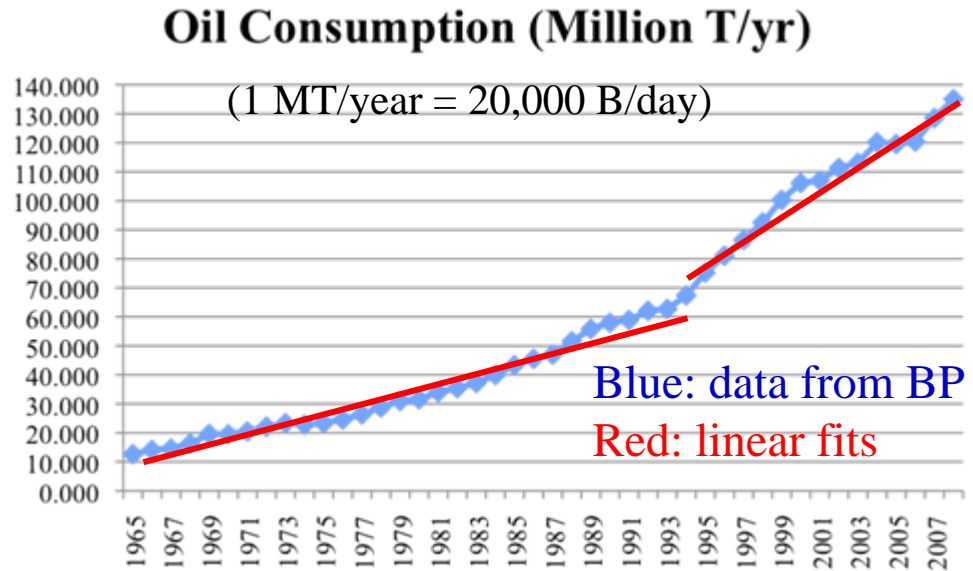
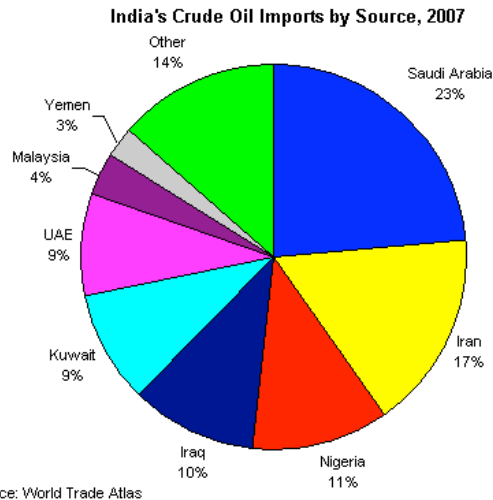
India's 3 Stage Nuclear Program



India's NP growth (my guess) : 4 → <40 GW capacity by 2032

Transportation Fuel

Crude Oil Consumption



- 2009 consumption \cong 3MB/day (production \sim 0.77 MB/day)
 - refining capacity \sim 3.6 MB/day \rightarrow 5.3 MB/day by 2013
- Average annual growth rate 1995-2008 \approx 0.1MB/day
 - Sustained by Imports (future?)
- Assume sustained BAU growth \rightarrow **6 MB/day by 2032**
 - India will need additional pipeline infrastructure

Summary: India's Energy Security highly compromised as it will need to import

- $> 90\%$ of crude oil
- $\geq 50\%$ of natural gas (even assuming new finds)
- $> 95\%$ of nuclear fuel (FBR and thorium cycle will still not be deployed in large scale)
- 25-33% of coal (? growth in global trade ?)
- Growth in hydro vulnerable to climate change

Urgent need for careful planning, investment, incentives aligned with a plausible end-state

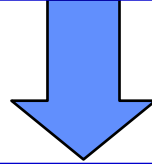
Current growth paradigm places India at risk with respect to energy and climate security and environmental degradation

- **Is the current development based on growth in use of fossil fuels a reasonable *tactical* strategy?**
 - **YES *provided*** *commitment to energy efficiency and transition to carbon-neutral energy systems is demonstrated wherever doable and the transition reaches a sustainable threshold by 2032*
- **Distributed renewable generation addresses all three – energy security, climate change, environment. But**
 - Need innovation to make renewable generation cost-effective
 - Need a paradigm change in the electric grid → smart green grid
 - Need socialization through education, demonstration, deployment

India has huge margin for reducing energy intensity and emissions intensity

Transition: Rethink how energy is produced/used

An era dominated by Fossil Fuels



Fossil Fuels as backup and storage

- **Transport:** Electric with gasoline as backup (eg. hybrid cars)
- **Heating & Cooling:** Solar thermal, heat pumps, evaporative coolers
- **Power Generation:** Renewable Generation and Nuclear
(Gas CHP & Hydro as backup)
Distributed Generation & Storage
- **End-use Efficiency:** Best Practices (education and common sense)
Load and demand management and balance
Smart Grid

Invest in 7 Science Grand Challenges Globally : **Innovation is key**

- **Carbon neutral use of fossil fuel (especially coal)**
- **Economic Solar and Wind (\$1/watt_p)**
- **Storage and Transmission of electric power**
- **Closed nuclear fuel cycle to enable safe, secure, sustainable nuclear energy**
- **H₂ / liquid fuel produced from non-fossil sources**
 - From Photochemical and/or thermal splitting of H₂O
- **Biofuels ⇐ Pest-resistant, self-fertilizing, low water using, easily degradable biomass**
- **Fusion – the ultimate “source”. Still 50 years away!**

What should India go to Copenhagen with

Policies and Treaties should be

- Equitable
 - both for countries and people within countries
- Measureable and Verifiable
 - Minimal need for monitoring ↔ transparency
- Aligned with existing/plausible technologies
- Cost-effective
- Incentivize good behavior and not be punitive
- Lead to a long term vision/end-state
 - Midterm (2032): Fossil fuels as backup
 - Long-term (2050+): Carbon-neutral

Global Win-Win Options: Power Generation

- Improve efficiency of coal & gas power plants
 - Coal-fired: subcritical → Supercritical → Ultra supercritical (~30% → 45%)
 - Gas turbines → CCGT → CCHP
- Utilize waste heat from coal and nuclear power plants
 - Heating (minimal need in India)
 - Industrial processes (co-locate power plants and industry)

Post 2032 as R&D needed for cost reduction & deployment

- Carbon Capture (in its infancy)
- Carbon sequestration (Aquifers, EOR, ...)
 - Insufficient capacity on the Indian sub-continent
 - Bay of Bengal: in 3000 meters of water (unproven and expensive)
- Carbon sequestration (Mineralization)
 - Research needed for using fractured basalt in Deccan plateau
- Carbon sequestration (Forestation)
 - A fast growing forest sequesters ~20 Tonnes of carbon per year per hectare (To sequester 1 GT of C → 50 M hectares)
 - Current size of agricultural land in India = 180 M hectares
- > 20% Renewable (Solar, Wind, Geothermal, Biomass) Generation

Global Win-Win Options: Transportation

- Public Transport
 - Build effective public transport systems as India urbanizes
 - De-incentivize single occupancy transport (i.e. cars for commuting)
- Require all autos, taxis, buses to run on CNG → Hybrids → Electric
- **Require all-car average > 25 km/liter by 2030**
- Long haul movement of goods by train rather than by trucks

Technology already exists

Global Win-Win Options: Unconventional

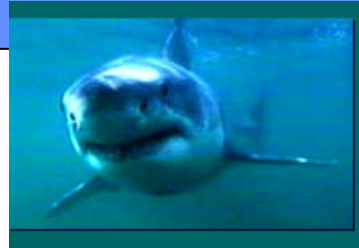
- **Population stabilization**
 - @0.5 kW per person → 5 tonnes CO₂/year of coal-fired power
 - Zero population growth in India → 200 million less people in 2032 = 1 GT CO₂
- **Reduce emissions of black carbon and ozone precursors**
 - Replacing biomass/dung stoves with LPG/kerosene
 - Poorly combusted diesel in transport sector (fuel additives, catalytic convertors)
- **Increase end-user energy efficiency and eliminate waste/loss**
- **Increase albedo of manmade structures (paint them reflective white)**
 - A not so flippant example of geo-engineering

India needs to implement all of the above until technology provides cost-effective carbon-neutral options

A macro view of global population

2.2 billion in 21st century

Healthcare
Food
Education
Energy
Water
Job Skills



1.5B in
Transition.

Most
Vulnerable
to Change

3 billion in 18th century

Living on less than \$2_{ppp} /day

(Additional 3.0B will start here)

Why EU, Japan, ... are well placed to go Green

No population growth + improved efficiency \Rightarrow phased replacements of fossil fuel plants in step with technology

Public transport systems are effective and used by a large fraction of the population

Missing Still

Incentives and education towards more fuel efficient cars and reduction in consumption

Nuclear Power hampered in countries where financial risk falls on private investors! What does this imply for R&D and long-term growth?

A firm commitment to doable win-win goals for which technology exists puts India on the right track to address both its energy and climate security challenge.

India must also continue to participate in the worldwide R&D effort to develop technology leading to cost-effective carbon-neutral solutions. (IPR)

For planning (efficiency) and public
buy in (to re-evaluate consumption)
need precise, transparent, multi-scale
data for

- Integrated lifecycle analysis
- Technology options
- Financial options
- Matching supply to demand
- End strategy

Global Energy Observatory (GEO)

URL <http://openmodel.newmexicoconsortium.org>

Goal 1: to assemble, annotate, store and analyze global energy systems

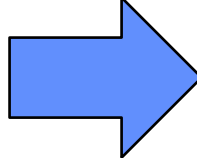
Goal 2: understand the dynamics of change in various energy systems

Goal 3: inform, educate & influence the transition to affordable carbon neutral energy systems



4 linked databases:

1. Power Plants
2. Fuels and Resources
3. Energy Transmission
4. Reducing Our CO₂ Footprint



*You can
do this
analysis*

GLOBAL ENERGY OBSERVATORY

INFORMATION ON GLOBAL ENERGY SYSTEMS & INFRASTRUCTURE

ACCELERATE THE TRANSFORMATION TO A WORLD WITH CLEAN ENERGY FOR ALL

Developed with Harihar Shankar (LANL Research Library)

<http://openmodel.newmexicoconsortium.org>

GEO: An open one-stop site for information on global energy systems

Goal: Facilitate policy, planning, analysis, education → Cheap Clean Energy

Power Plants (GEOpower)



- ✓ Coal Plants
- ✓ Gas Plants
- ✓ Geothermal Plants
- ✓ Hydroelectric Plants
- ✓ Nuclear Plants
- ✓ Oil/Diesel Plants
- ✓ Solar PV Farms
- ✓ Solar Thermal Plants
- ✓ Waste Plants
- ✓ Wind Farms

Fuels & Resources (GEOresources)



- ✓ Gas Fields
- ✓ Oil Fields
- ✓ Coal Mines
- ✓ Uranium Mines
- Crude Oil Refineries
- ✓ Solar Potential
- ✓ Wind Potential
- ✓ Biomass resource
- ✓ CO₂ Sequestration

Transmission (GEOtransmission)



- ✓ Gas Pipelines
- ✓ Oil Pipelines
- ✓ Coal Ports
- ✓ LNG ports
- ✓ Oil Ports
- ✓ Rail Links
- ✓ Road Links
- ✓ Shipping Lanes
- Electric Power Grid

Reduce Your CO₂ Footprint



- ✓ CO₂ Footprint Calculator
- ✓ Reduce Footprint
- ✓ Renewable Systems
- ✓ Storage
- Smart Grid

✓=done, =Partially Done, =under construction

GEO -- an open web tool for integrated analysis:

1. Planned growth in coal, nuclear, hydro, gas, waste power plants → sustainable

2. Long-term Optimization: Energy & Climate security in Generation, Fuels and Resources, & Transmission

3. Improve Efficiency in Generation, Transmission, End-use → Development

4. Incentives to integrate renewables → smart green grid.



Conclusions

- BAU (reliance on fossil fuels) is not a sustainable option
-- *Fallback: rely on Russia for coal, gas, nuclear & political firewall*
- All 3 – energy security, climate change and environmental protection – highlight the need for a paradigm shift in energy planning, investment and use.
- There exist significant global win-win options that reinforce development and address climate change. These options are daunting but doable. Challenge is implementation.
- Alternative energy resources are maturing. Need R&D for cost-reduction, storage options and integration into grid.
- Global investment in R&D and technology transfer is essential