

Expanding Nuclear Energy Without Increasing the Risks of Nuclear Proliferation

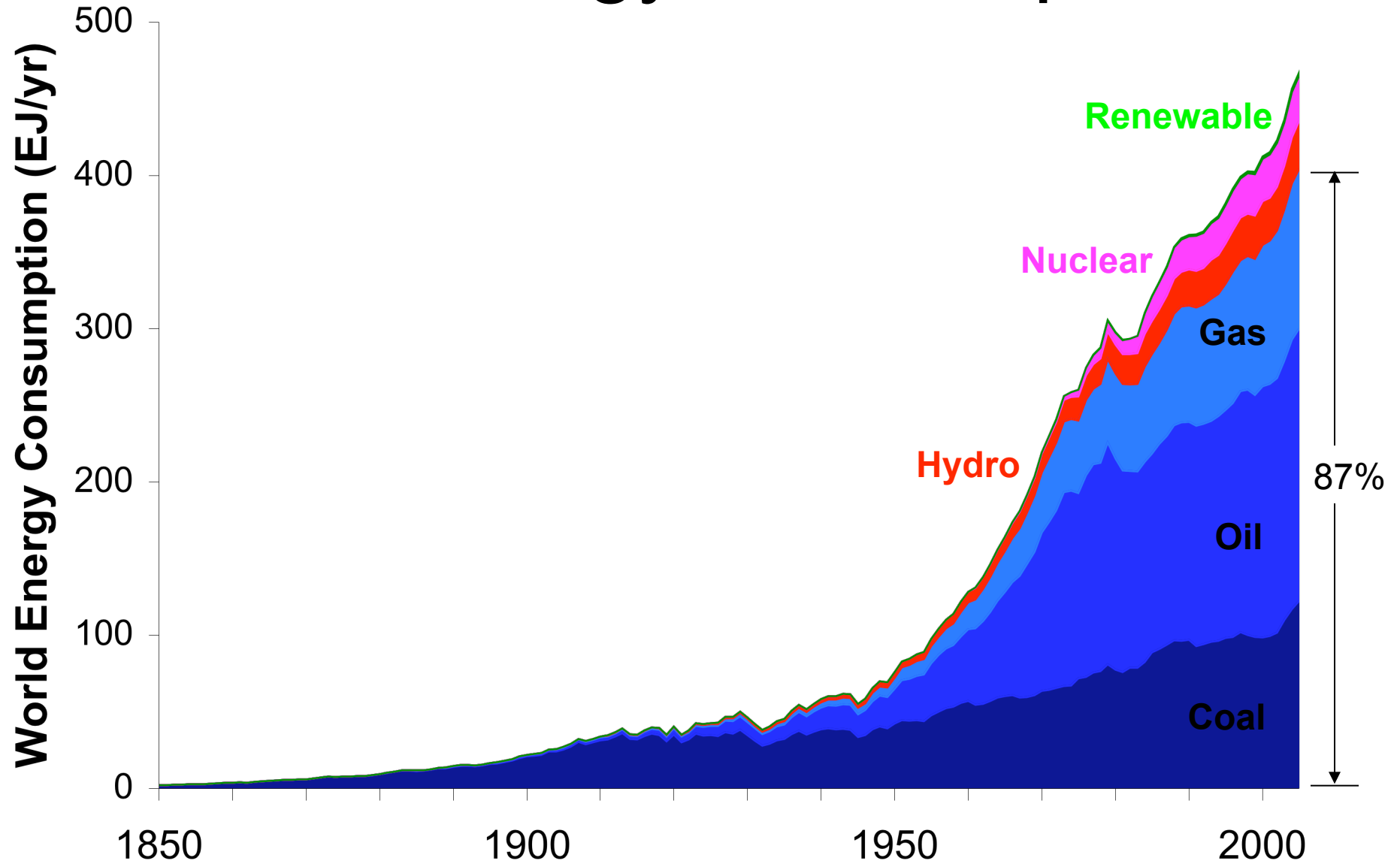
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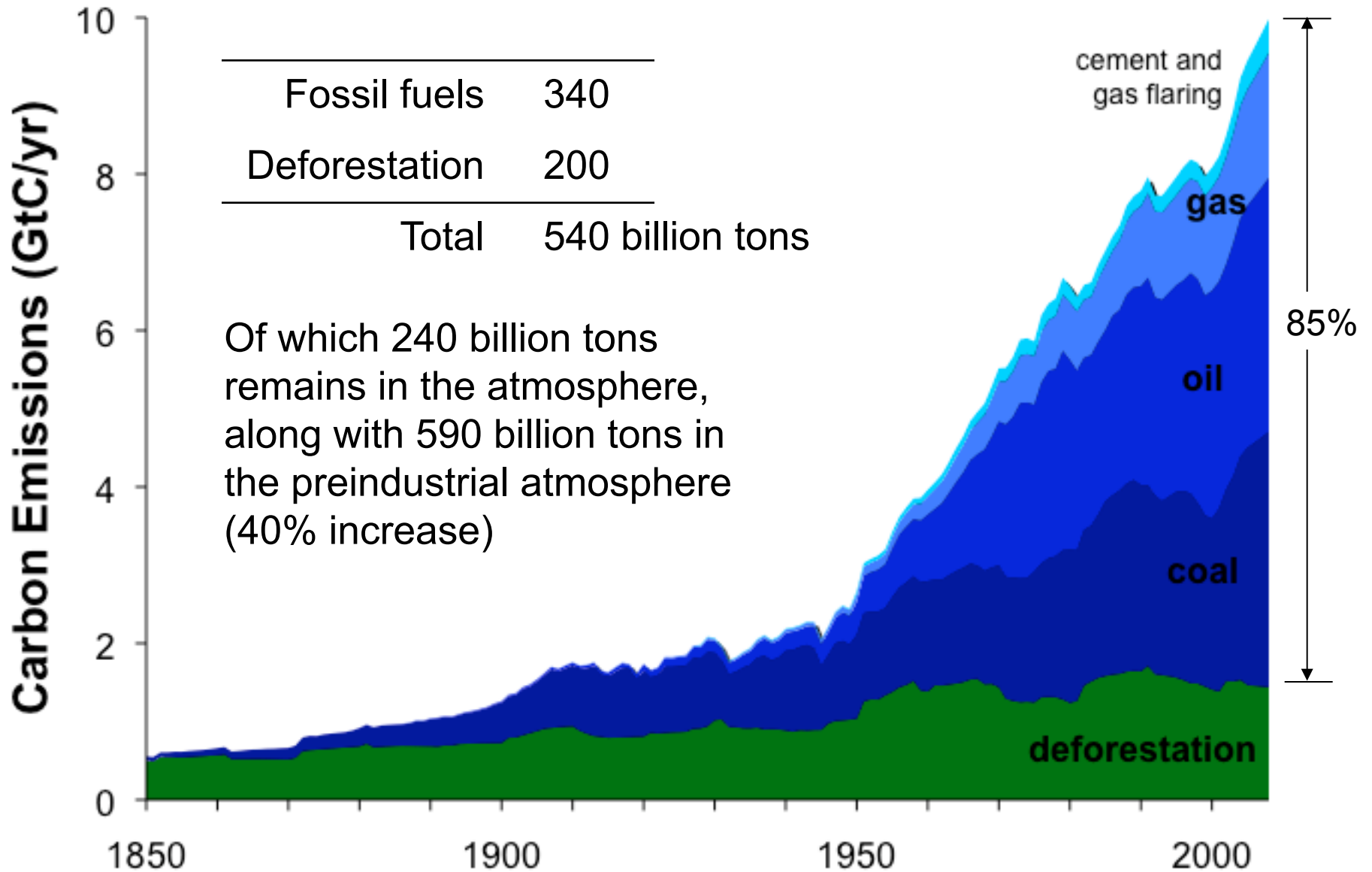
What Is the Problem?

- Carbon emissions must be reduced substantially to stabilize greenhouse gas concentrations
- World energy consumption must increase greatly to accommodate development of poorer countries
- Achieving both will require massive growth in low-carbon energy supply over next 50 years
- Nuclear energy is largest low-carbon source today, is readily expandable by a large factor, and has important advantages over low-carbon alternatives
- A large-scale expansion raises serious concerns about nuclear proliferation and terrorism

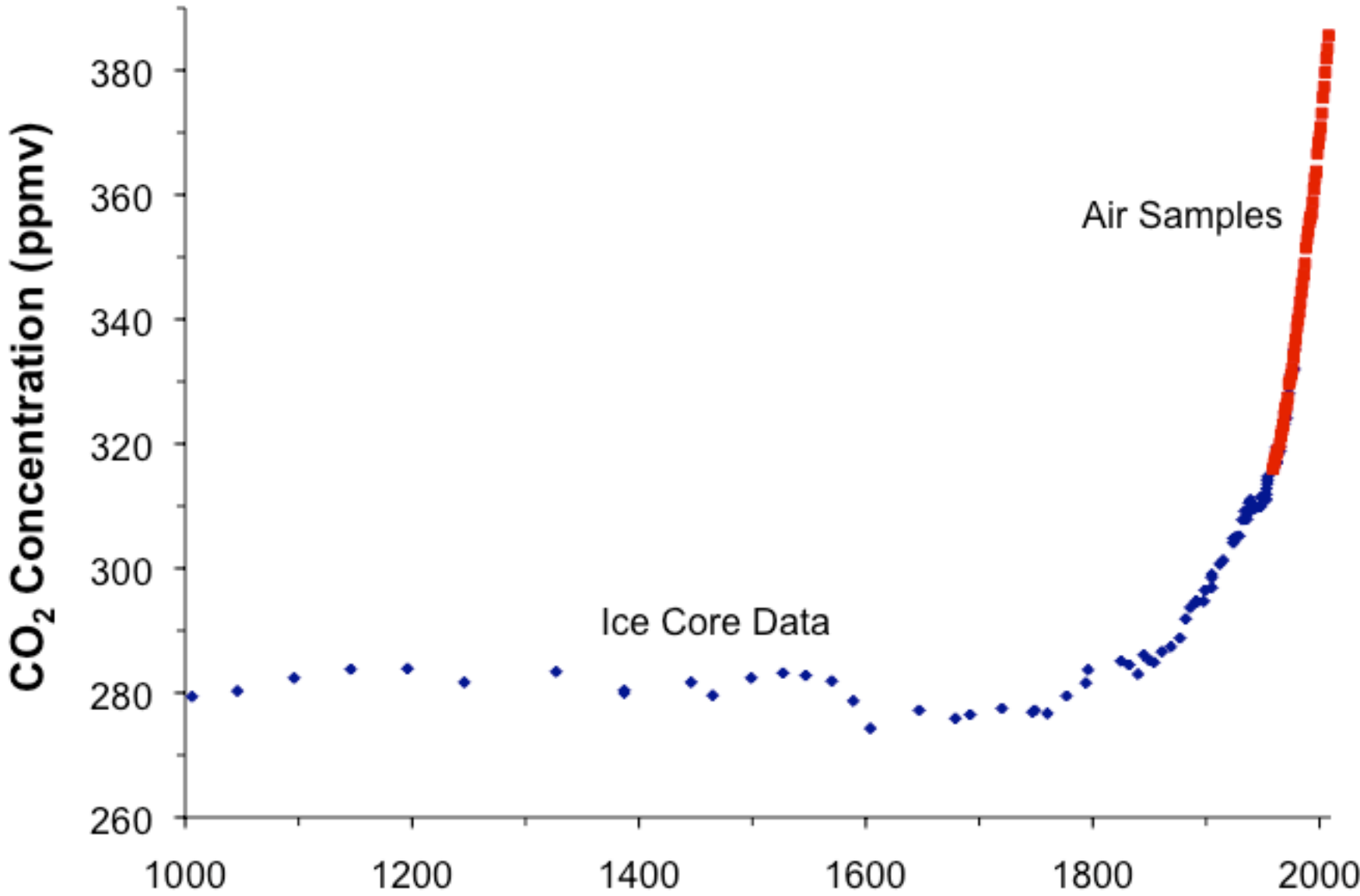
World Energy Consumption



World Carbon Emissions



Carbon Dioxide Concentration



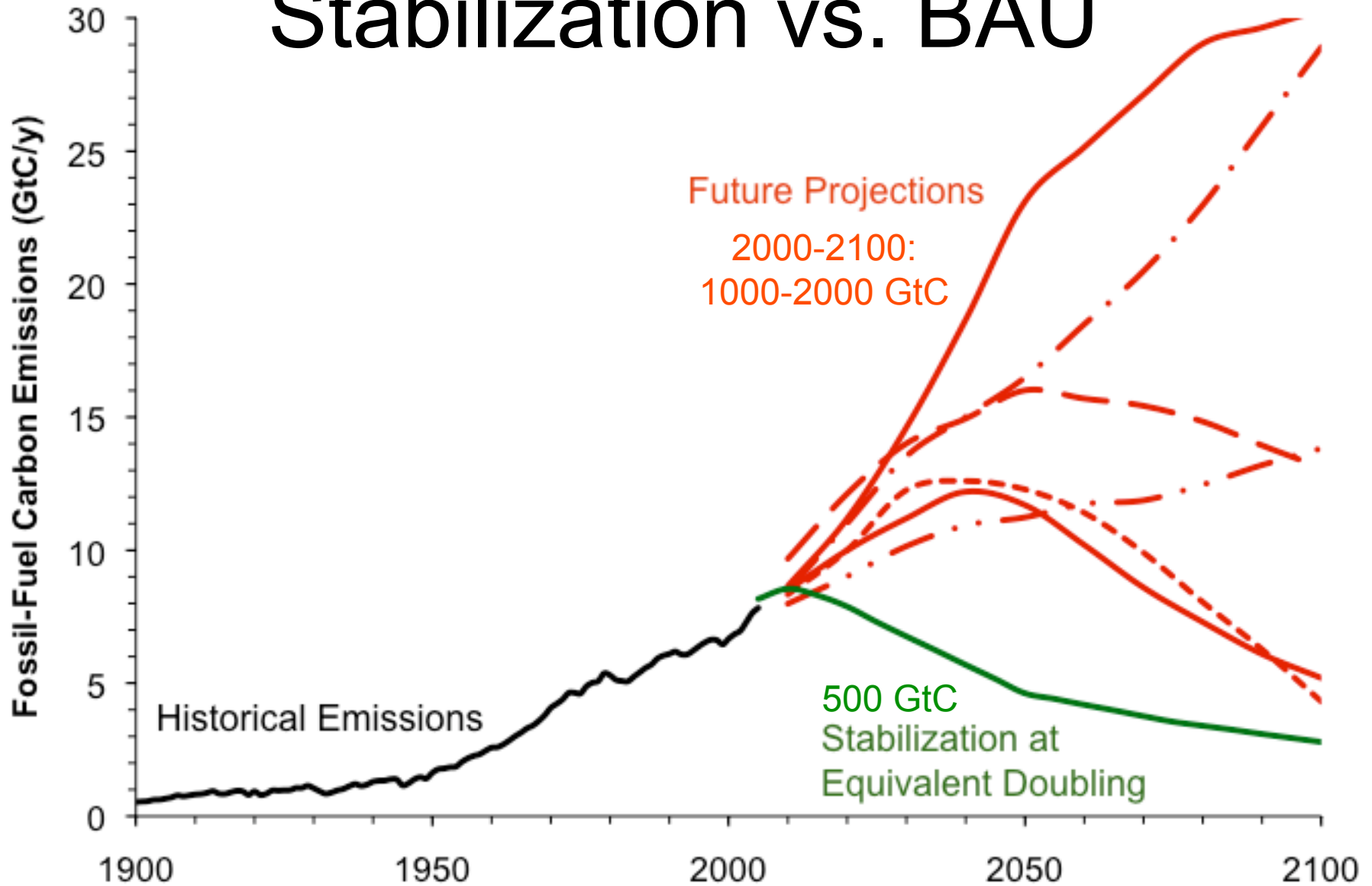
UN Convention on Climate Change

Article 2. The ultimate objective is to achieve **stabilization of greenhouse gas concentrations** in the atmosphere at a level that would **prevent dangerous anthropogenic interference** with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

The Stabilization Goal

- “Dangerous interference” now seems inevitable; the challenge is to avoid “catastrophic” change
- A doubling of carbon dioxide would lead to an temperature increase of 2 to 4.5 °C
 - at low end, twice what we have already experienced
 - at high end, very severe impacts likely; true catastrophe seems unlikely—but not impossible
- We must also account for other greenhouse gases
- To stabilize at “equivalent doubling,” we must emit only 500 billion tons of carbon in this century

Carbon Emissions: Stabilization vs. BAU



Main Alternatives to Nuclear

Demand reductions	Necessary, but taxes and efficiency alone cannot achieve required reductions
Biomass	1 billion ha (current crop harvest) could yield 300 EJ/y (current oil & gas), but energy crops compete with food and nature
Wind	Electric only; limited to 10-20% of supply without inexpensive storage
Solar	Expensive; electric only; limited to 10-20% without inexpensive storage
Carbon sequestration	Safety & stability concerns; CO ₂ capture, disposal costs are purely additional

Other Low-Carbon Alternatives

Hydropower	Large expansion not possible, significant environmental impacts
Geothermal	Only hot-water geothermal possible today; limited and exhaustible resource
Fusion	Cannot be commercially available on significant scale by 2050
Ocean	Tidal and wave power are limited and have significant environment impact; ocean thermal has extremely low efficiencies; all are expensive

Advantages of Nuclear

- Largest installed base of low-carbon energy, extensive operating experience and industrial base
- Unlike wind and solar, can provide baseload electricity
- Unlike biomass, low environmental impact
- Unlike carbon sequestration, ready now
- But lots of nuclear will be needed to make a significant contribution...

Growth Scenario for Nuclear

Provides ~25% of carbon reduction needed for stabilization at an equivalent doubling

	2005	2025	2050	2100
Build rate (GW_e/y)	3	35	70	100
Installed capacity (GW_e)	370	500	1500	4500
Electricity generation (% world)	15	15	20-25	25-50

Key Issues for Nuclear

- **Cost**
 - high and uncertain capital cost, but nuclear should be competitive with alternatives at \$2000/kW_e
- **Safety**
 - If new LWRs 10x safer, 30-60% chance of core melt, 3-8% of release by 2100 in high-growth scenario
- **Waste**
 - storage and geological disposal are safe, inexpensive
- **Proliferation**
 - expansion must not make it significantly easier for countries or groups to acquire weapons

Nuclear v. Alternatives (\$/MWh)

	nuclear	coal	gas	wind	solar
Capital	50	30	12	60	250
O&M	15	5	3	10	5
Fuel	5	10	25-50	0	0
Total	70	45	40-65	70	250
+ \$100/t_c	0	25	12	0	0
Total w/tax	70	70	52-77	70	250

plus backup/storage
above ~20% of load

Proliferation Risks

- Fresh fuel, reactors, and spent fuel are easy to safeguard, highly resistant to diversion and theft
- Uranium enrichment
 - separative work required to fuel 1 reactor with LEU could be used to produce HEU for 25 bombs/year
 - HEU production readily detectable in known facilities, but clandestine enrichment is very difficult to detect
- Reprocessing
 - spent fuel discharged by 1 reactor contains enough Pu to build 25 bombs/year—protected by high radiation
 - if spent fuel is reprocessed, separated Pu or Pu fuels are vulnerable to diversion and theft

Increasing Proliferation Resistance

- Improved safeguards
 - even if successful, virtual nuclear states will generate severe breakout concerns
- Institutional options
 - fuel banks and other supply assurances
 - fuel leasing and spent-fuel take-back
 - restrict enrichment, reprocessing to select countries
 - multinational ownership or international control of sensitive fuel-cycle facilities, use of fissile materials
- Technological options
 - alternative reactors and fuel cycles
 - small sealed-core reactors

Reliable Fuel Supply

- It is reasonable for a country to pay a premium to ensure fuel supply for an expensive reactor
- A guaranteed supply of fresh fuel should discourage both enrichment and reprocessing
- Fuel banks are intended to provide this guarantee
- But commercial markets already work well in providing long-term contracts at competitive prices for uranium, enrichment, and fabrication
- It is difficult to provide believable and ironclad guarantees of supply in situations where markets might not work due to political factors

Fuel Leasing and Take-back

- Fuel leasing, in which the supplier agrees to take responsibility for the spent fuel, would provide a very powerful incentive for countries to voluntarily forgo enrichment and reprocessing
 - take-back does not depend on reprocessing; long-term storage and/or disposal is cheaper
- Today, only Russia permits take-back
 - can other countries be encouraged to consider this?
 - international spent-fuel storage? repositories?
- Voluntary arrangements will not address hard cases (e.g., Iran), but can establish a new norm

Global Nuclear Energy Partnership

- Limit enrichment and reprocessing to “supplier” states (existing fuel-cycle states)
 - Argentina, Australia, Brazil, Canada, South Africa, Ukraine interested in being supplier states
- Supplier states provide fresh fuel to “user” states, take back spent fuel
- Supplier states reprocess spent fuel and use separated TRU as fuel for fast reactors
 - believed by advocates to be necessary to make take-back politically possible, but that is not clear

Multinational Ownership

- Encourage multinational ownership of enrichment and reprocessing facilities
 - Facility in technology-holder state: allow part ownership in exchange for guaranteed supply
 - not very different from long-term contract; unlikely to significantly change incentives
 - Facility in other states: use “black box” technology, limit access to citizens of technology-holder state
 - may not be acceptable to many host states

International Control

- Require that all enrichment and reprocessing facilities be owned and operated, and all non-military stocks of fissile material be owned and used, by an “international nuclear authority”—the 1946 “Baruch Plan” revisited
- Unlikely under current arrangements, but...
 - Article IV of NPT: “inalienable right of all the Parties to use of nuclear energy for peaceful purposes”
 - Article VI of NPT: parties undertake to pursue “negotiations in good faith on nuclear disarmament”
 - Could restrictions on enrichment and reprocessing be linked to pursuit of prohibition of nuclear weapons?

Technology Alternatives

- No reactor type or fuel cycle is substantially more proliferation resistant than the once-through LWR
 - thermal recycle reduces enrichment, but encourages reprocessing and exposes MOX fuel to risks of theft
 - CANDU reactors eliminate enrichment but are difficult to safeguard, easier to divert to plutonium production
 - fast breeder reactors eliminate enrichment but require reprocessing and greatly increase flow of Pu fuels
 - spent fuel, reprocessing and fresh plutonium fuels cannot be made “proliferation resistant”
 - thorium fuels can reduce enrichment requirements and plutonium production, but not enough to constitute a qualitative advantage

Technology Alternatives

- Small sealed-core reactors
 - standard designs produced in factories
 - low power density, no possibility of core melt
 - shipped complete to site by rail car or barge with sealed, long lifetime core
 - returned at end of core life for recycle
 - economies of production can only be achieved with mass production; manufacture and fuel cycle become high concentrated (e.g., commercial aircraft)

Questions?