Climate Change and the Transformation of World Energy Supply

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In briefest summary…

- A serious effort to mitigate climate change would require increasing carbon-free energy supply 5-20x by 2050, from 15% to 40-80% of total energy
- Major contributions *could* come from:
  - nuclear fission
  - biomass
  - solar
  - wind
  - "decarbonized" fossil fuels
- All now have serious shortcomings; most urgent need is R&D to address these

The Ultimate Objective

"Stabilization of GHG concentrations at a level that would prevent dangerous anthropogenic interference with the climate system.

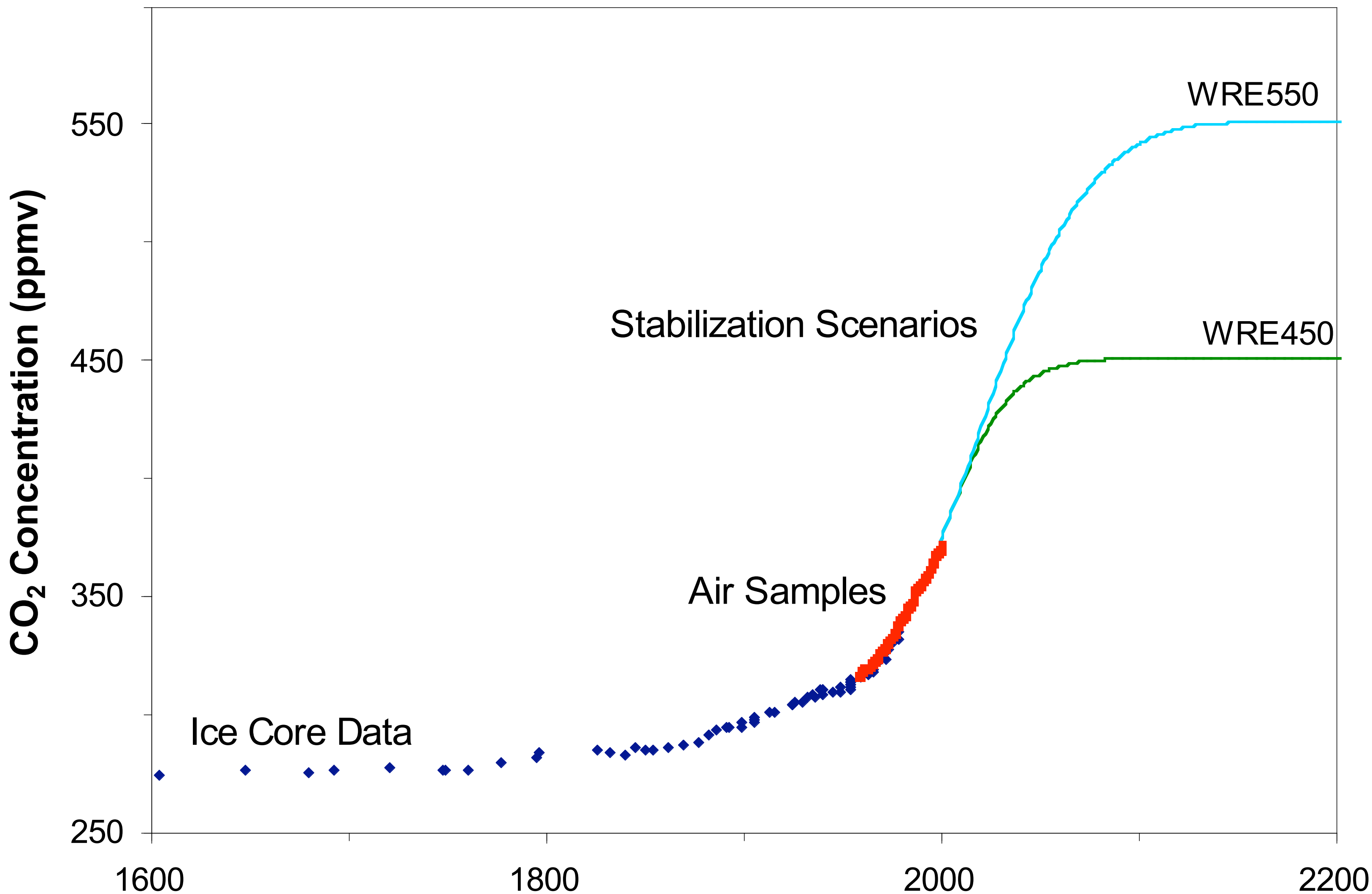
Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally, ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Article 2, UNFCCC

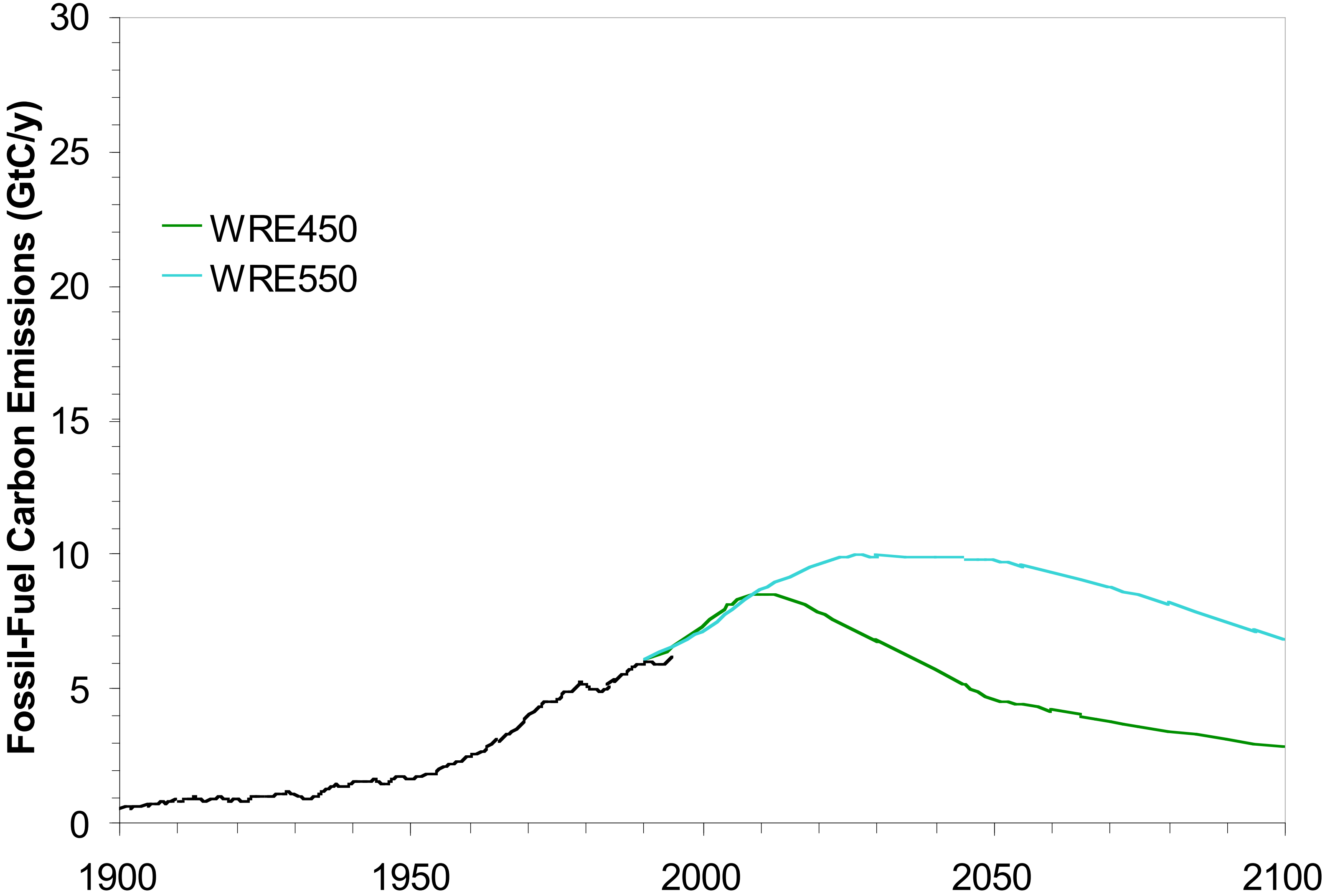
Stabilization Level

- What level achieves the UNFCC goal?
- Difficult to argue that levels above a doubling of CO_2 (550 ppm) would "prevent dangerous interference"
  - with other GHGs, equivalent to 650 ppm CO_2
  - "equivalent doubling" ≈ 450 ppm CO_2
- How must energy supply change to stabilize CO_2 at 450-550 ppm?

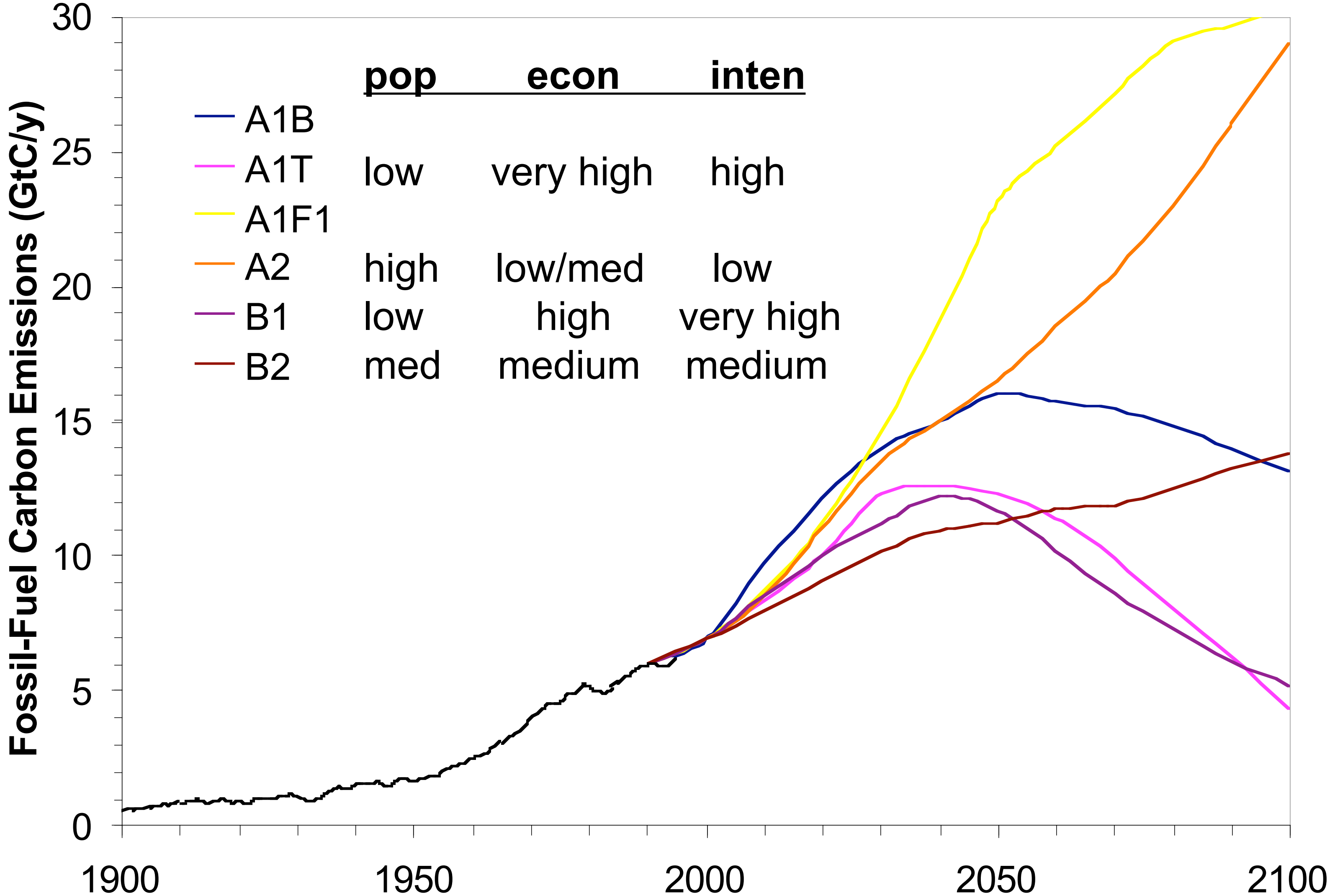
Stabilization Scenarios



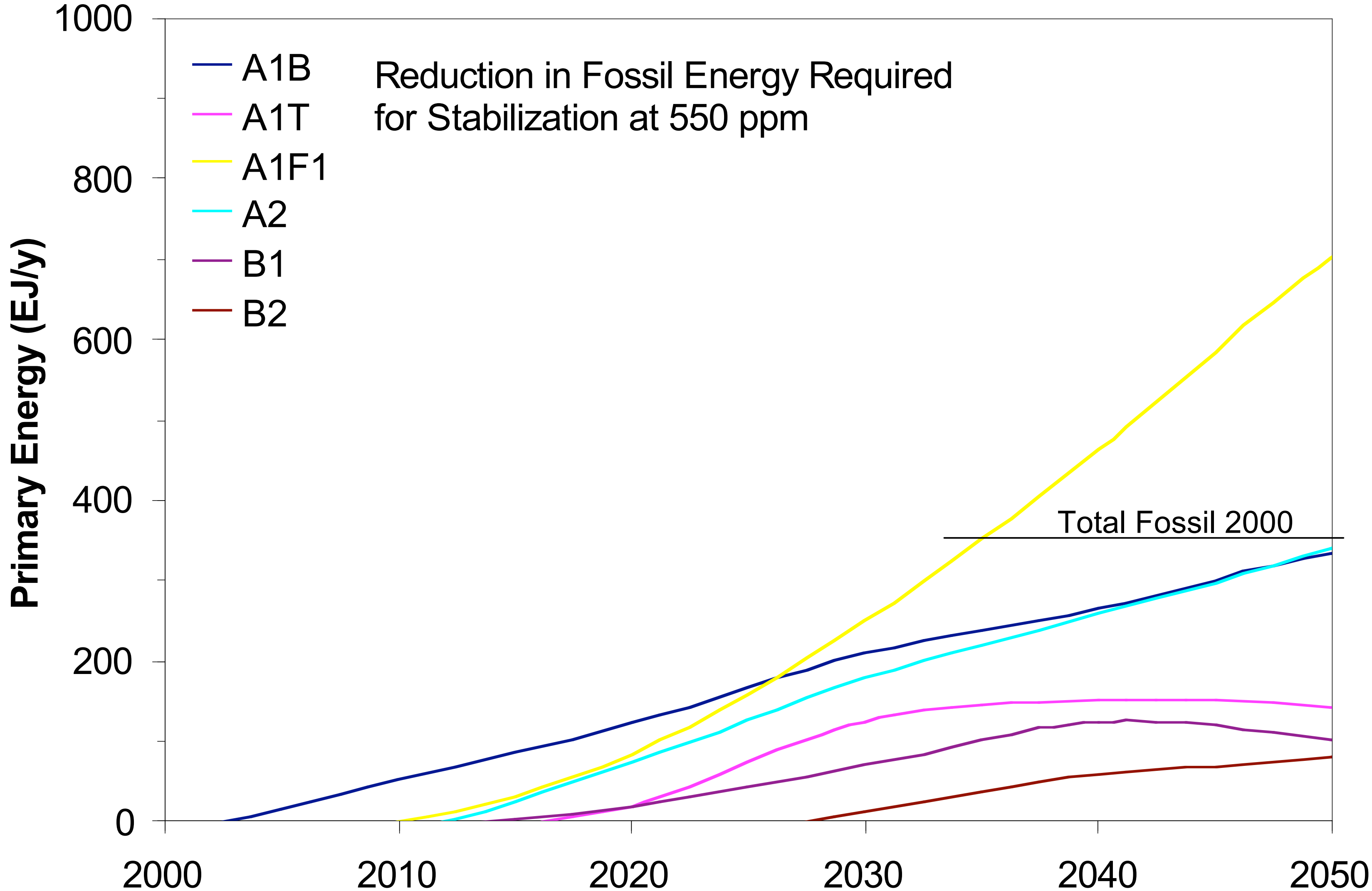
CO_2 Emissions to Stabilization



Reference Emission Scenarios



Fossil Reduction for 550 ppm



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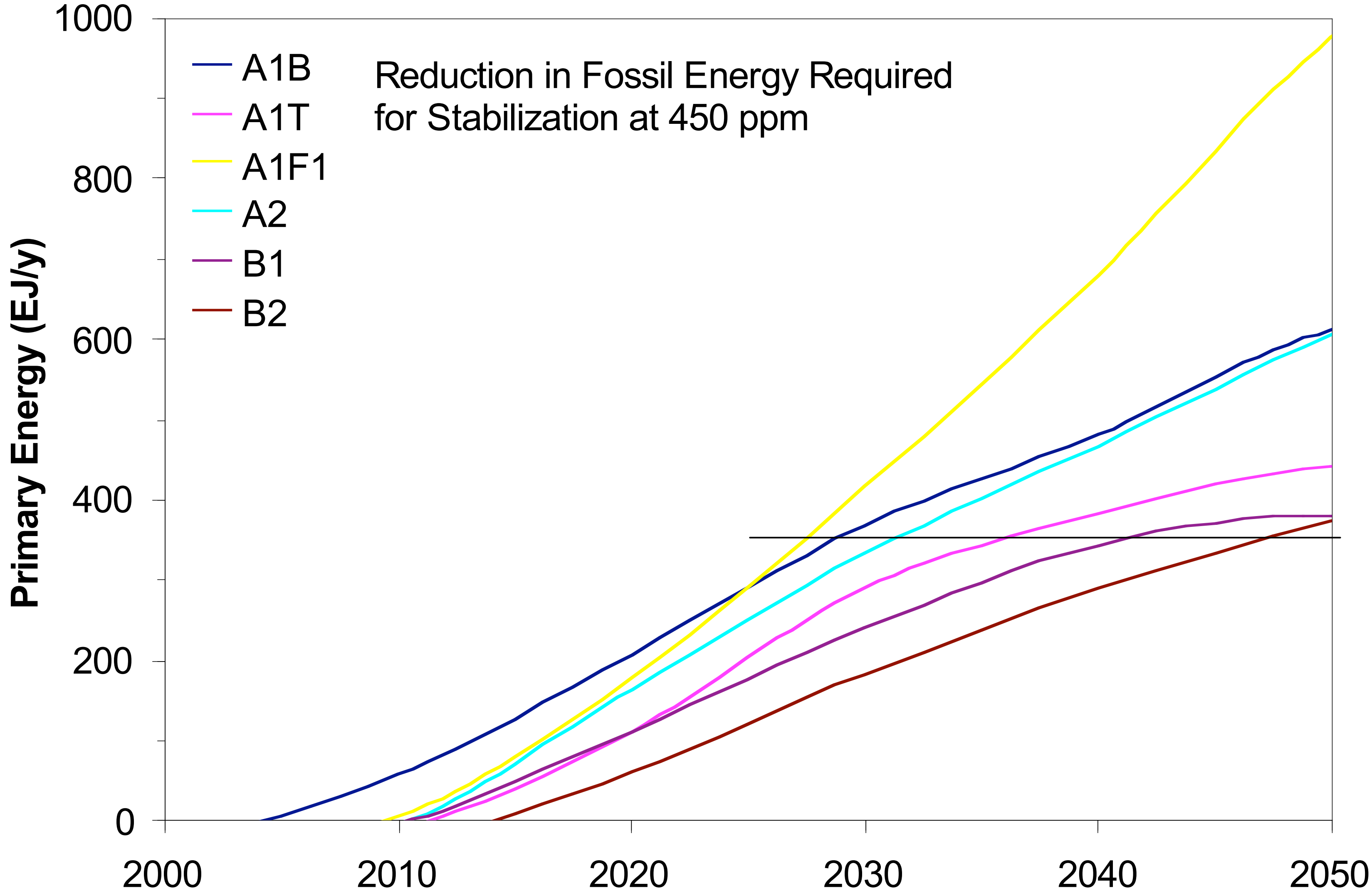
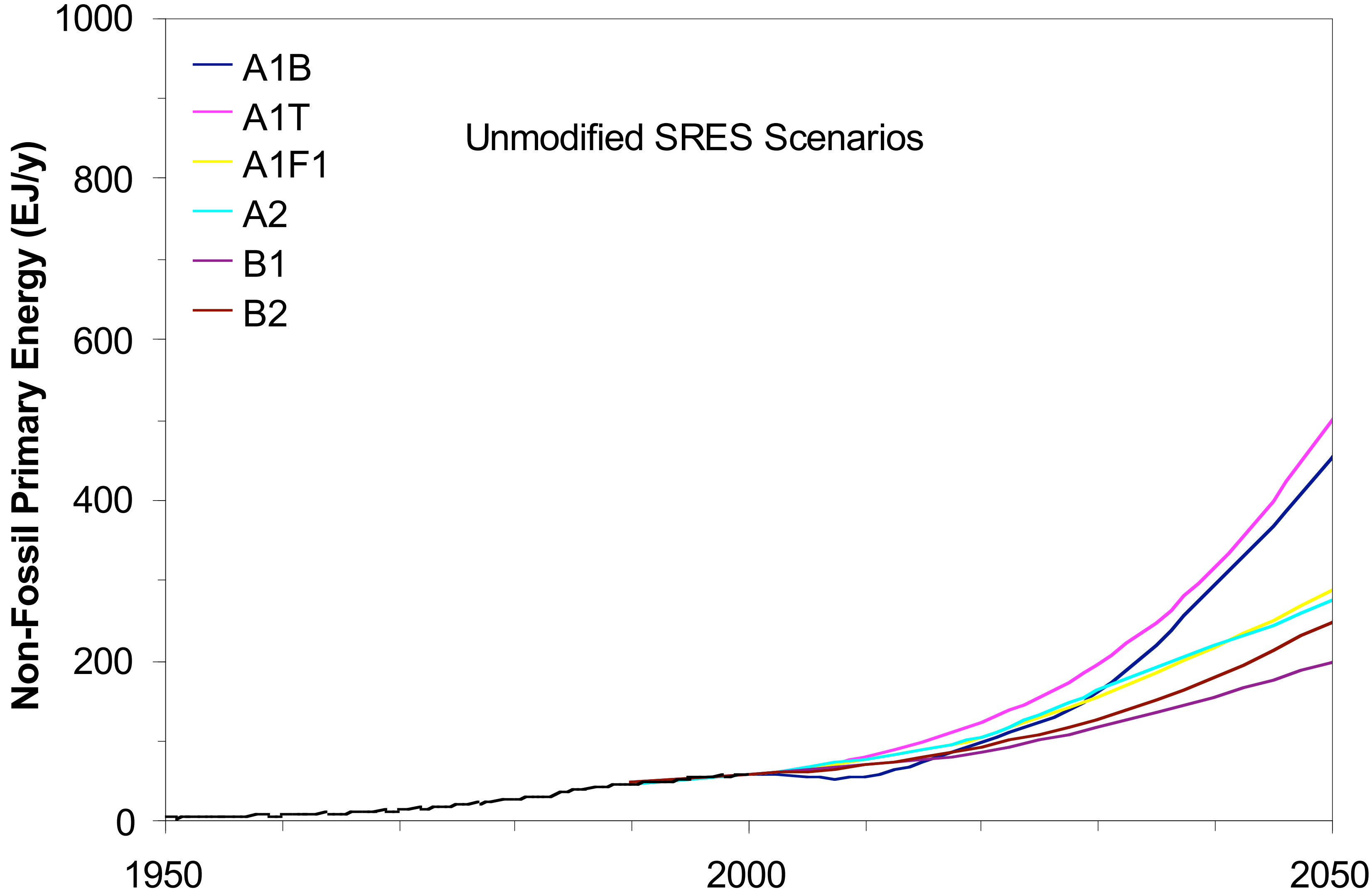
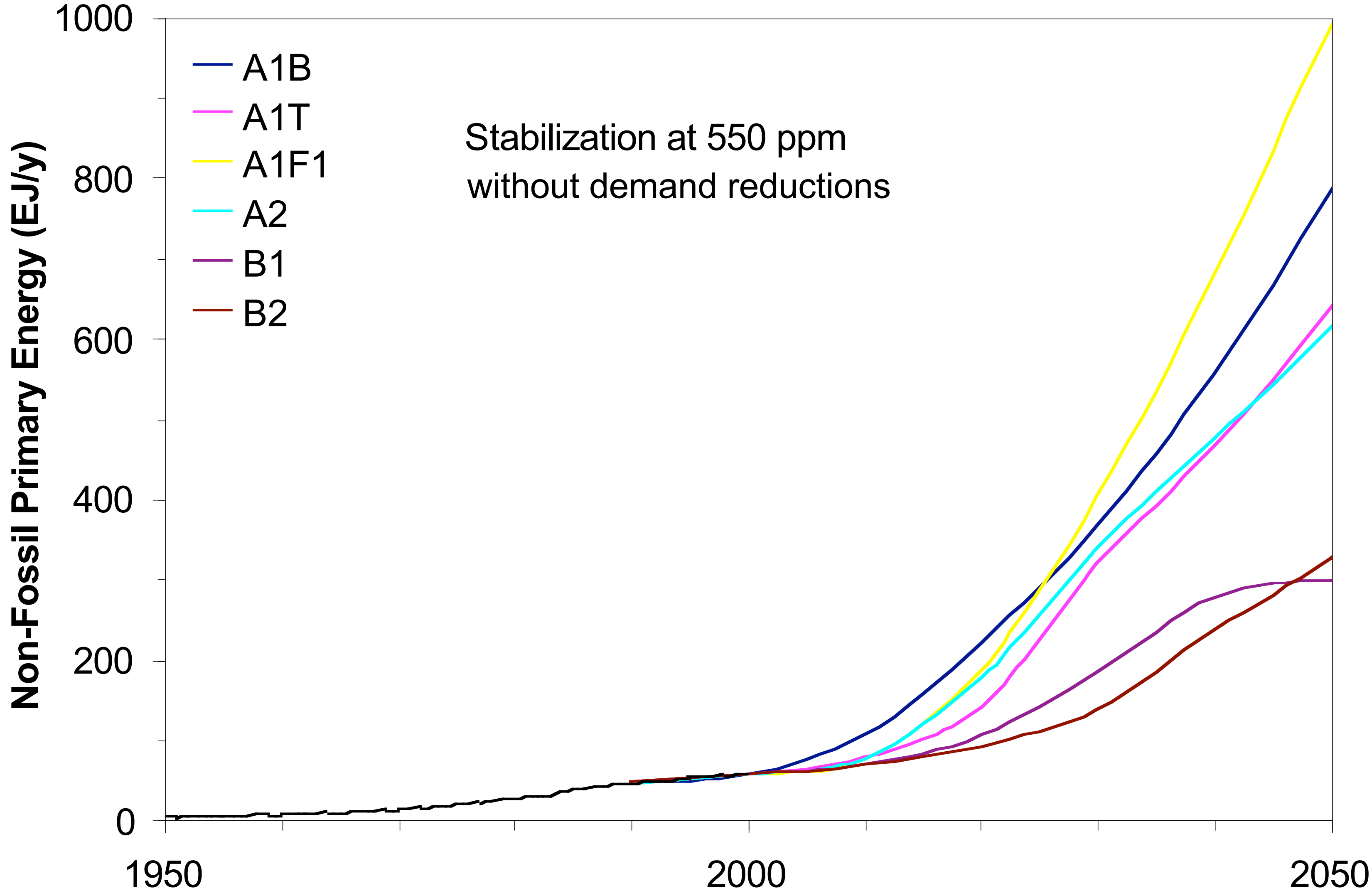


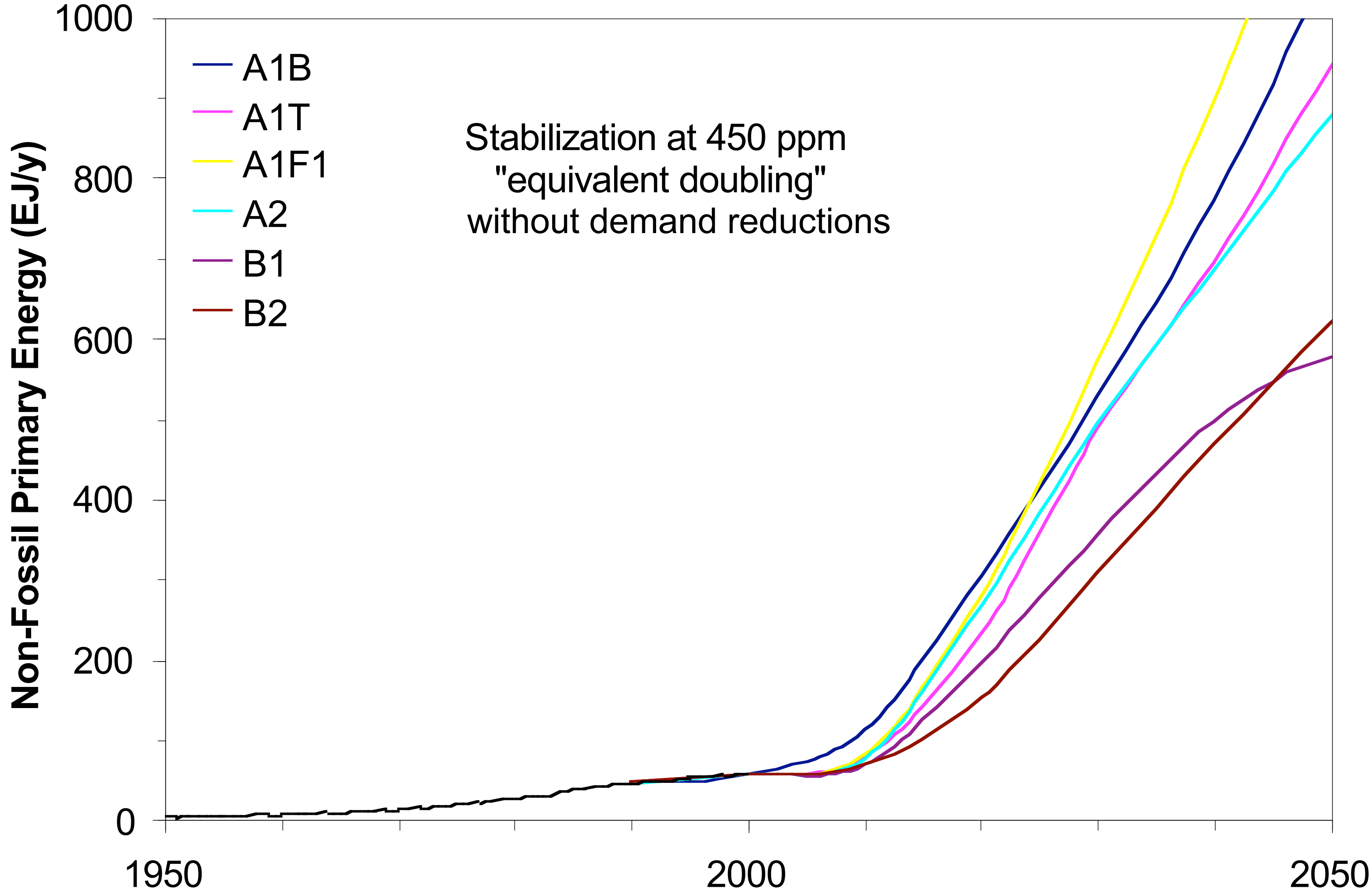
Non-Fossil: Reference Scenarios



Non-Fossil: Stabilization at 550



Non-Fossil: Stabilization at 450

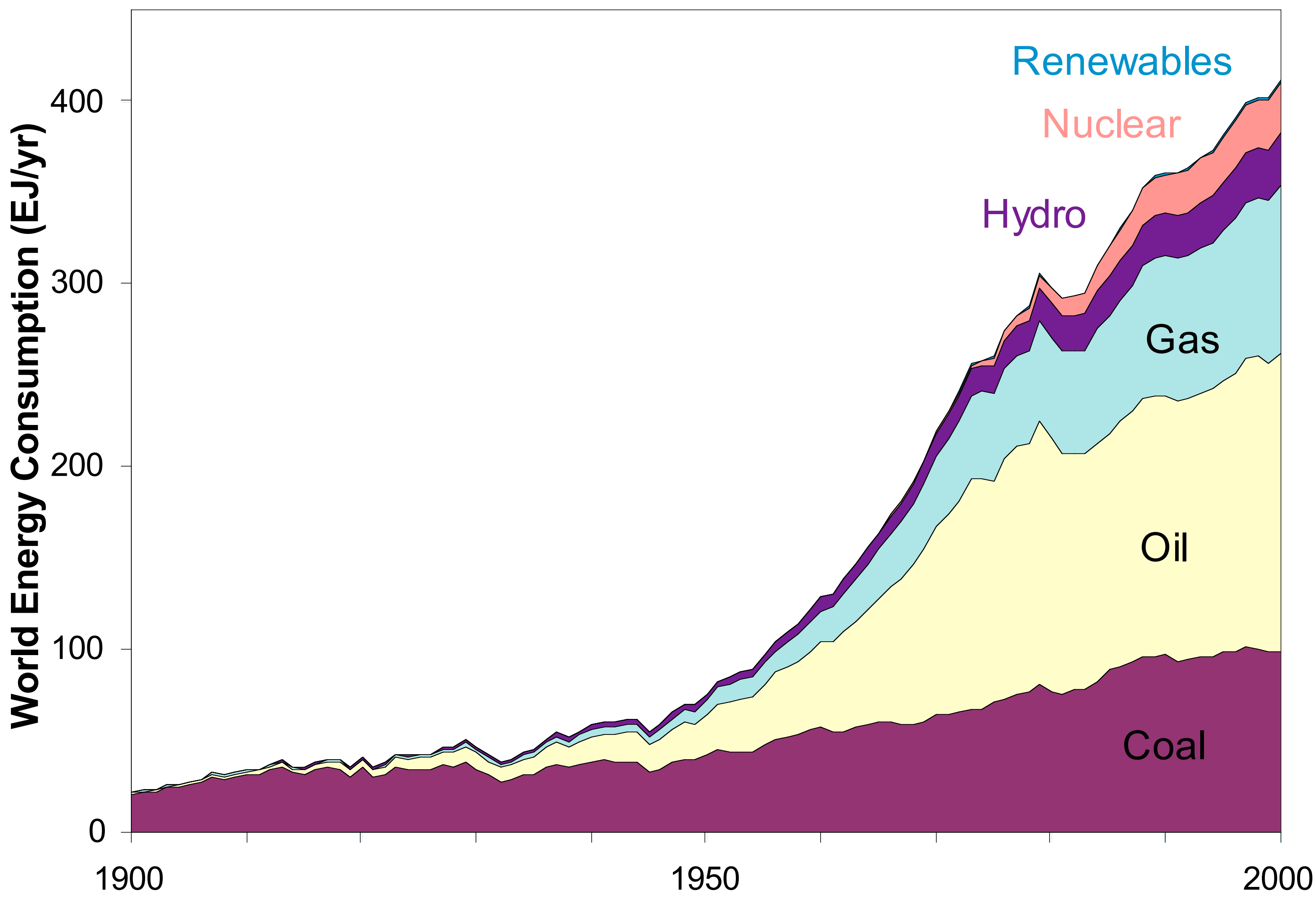


Growth of Non-Fossil Energy

		Primary Energy (EJ/y)	Non-fossil Share (%)	Growth Rate (%/y)
2000		58	14	2.3
2050	Reference	200- 500	20-40	2.5-4.5
	WRE550*	300-1000	35-65	3.5-6.0
	WRE450*	600-1300	70-85	4.5-6.5

*without demand reductions (i.e., carbon taxes or permits)

World Energy Use



300+ EJ/y of Carbon-Free Energy?

(1 EJ/y ≈ 10 GW_e ≈ 0.5 Prudhoe Bay)

- Not hydro
  - 29 EJ/y in 2000; could double or triple
- Not geothermal
  - 0.8 EJ/y in 2000; 5-20 EJ/y hot water possible
- Not nuclear fusion
- Not tidal, wave, or ocean thermal
  - 0.006 EJ/y in 2000 (tidal)
  - thermal resource large, but extremely low efficiency, huge technical challenges

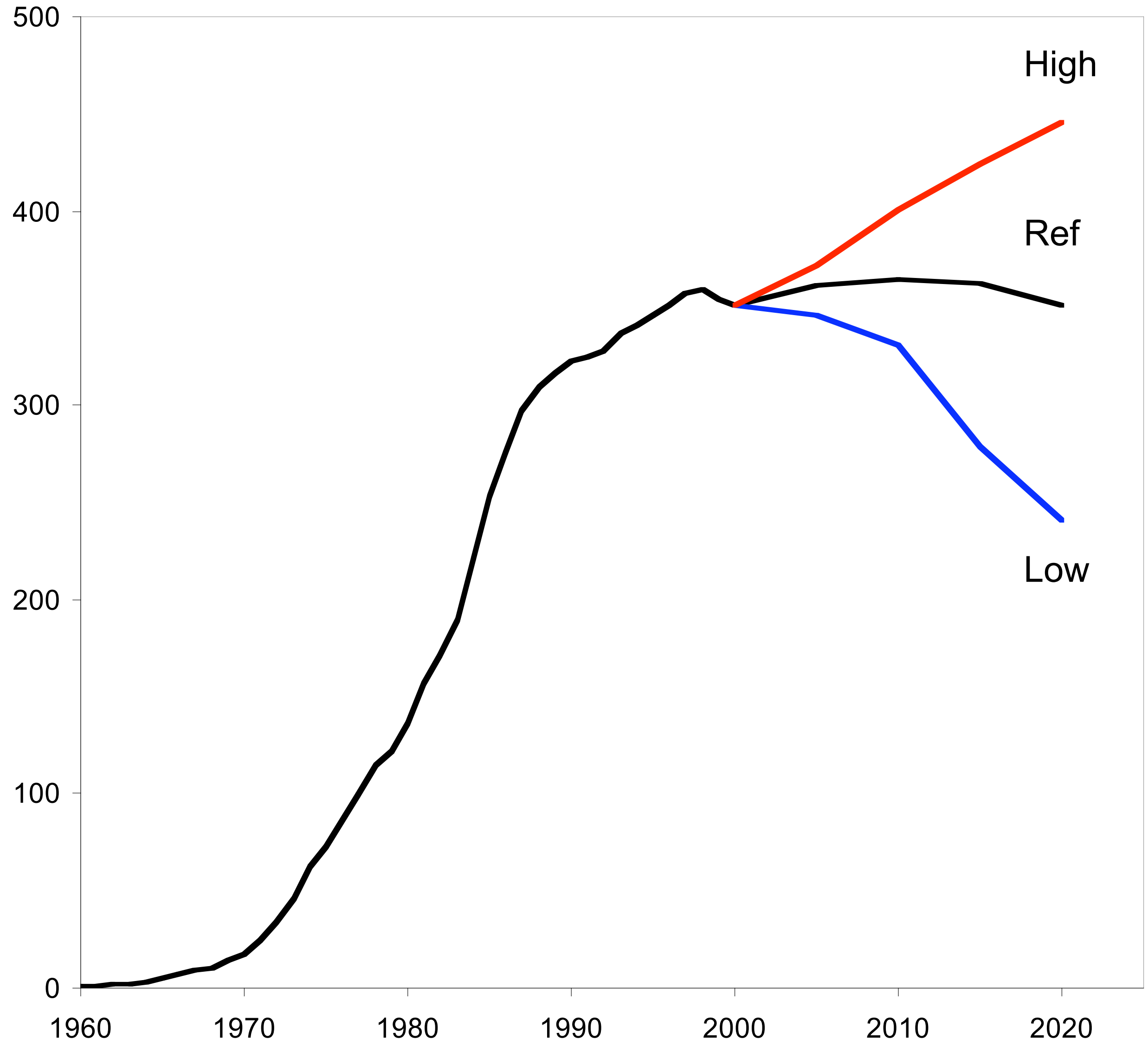
Potential Major Sources

- Nuclear fission
- Biomass
- Solar
- Wind
- Decarbonized fossil fuels

Nuclear Fission

- Already deployed on large scale
  - 437 reactors, 353 GW_e, 28 EJ/y
- Near-term prospects dim
  - significant growth unlikely for next 20 years
- To grow, four issues must be addressed:
  - capital cost
  - accident risk
  - waste disposal
  - proliferation

Installed Nuclear Capacity



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  Appropriate for developing countries?
- Electricity only (electrolytic H_2 very expensive)

Electrolytic H_2: too expensive?

Feedstock	**Cost**	**Contribution to H_2 Cost**
Electricity	$0.04/kWh	$14/GJ
Gas	$3/GJ	$5/GJ
Coal	$1.5/GJ	$7/GJ
Biomass	$4/GJ	$8/GJ

Biomass

- Mature technology, well-suited for developing countries
- Affordable portable fuels (liquids, H_2)
- Aggressive use of wastes ≈ 30 EJ/y
- 1000 Mha energy crops ≈ 300 EJ/y
  - 1000 Mha harvested for food
  - 500-1000 Mha potentially arable (80% tropical)
  - availability of land will depend on balance between growth in food consumption, yields

Wind

- 0.25 EJ/y in 2000, ~20%/y growth
- Mature technology, well-suited for developing countries (with a good grid)
- Electric only, intermittent
- Without storage, intercontinental transmission, practical limit roughly

  ≈ 100 EJ/y ≈ 40-100 Mha

  ≈ 10-20% world electricity in 2050

Solar

- 0.5 EJ/y in 2000 (mostly heat)
- High cost
  - Low-temperature heat
    installed costs ≈ \$400-2500/m^2 ≈ \$10-100/GJ
  - Electricity
    installed cost ≈ \$5/W_p ≈ \$0.2-0.5/kWh
- Intermittent source
  - 10% world electricity in 2050 ≈ 50-100 EJ/y
    ≈ 2-4 Mha sunny land

Decarbonized Fossil Fuels

- Recoverable resources are huge:
  ~10^5 EJ conventional, ~10^6 EJ unconventional
- Huge existing industrial base
- Electricity or portable fuels,
- Cost, environmental impact of CO_2 separation, transport, and disposal

“Prediction is very difficult,
especially about the future.”

“If an idea does not appear bizarre,
there is no hope for it.”

– Niels Bohr