Perspectives on Greenhouse Gas Emissions and Energy Payback Ratios for Fusion Power

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Objective

- **Calculate the Energy Payback Ratio (EPR) for Coal, Natural Gas, Fission, Wind, and DT Fusion Electrical Power Plants**

  Perform "Birth to Death Analysis"

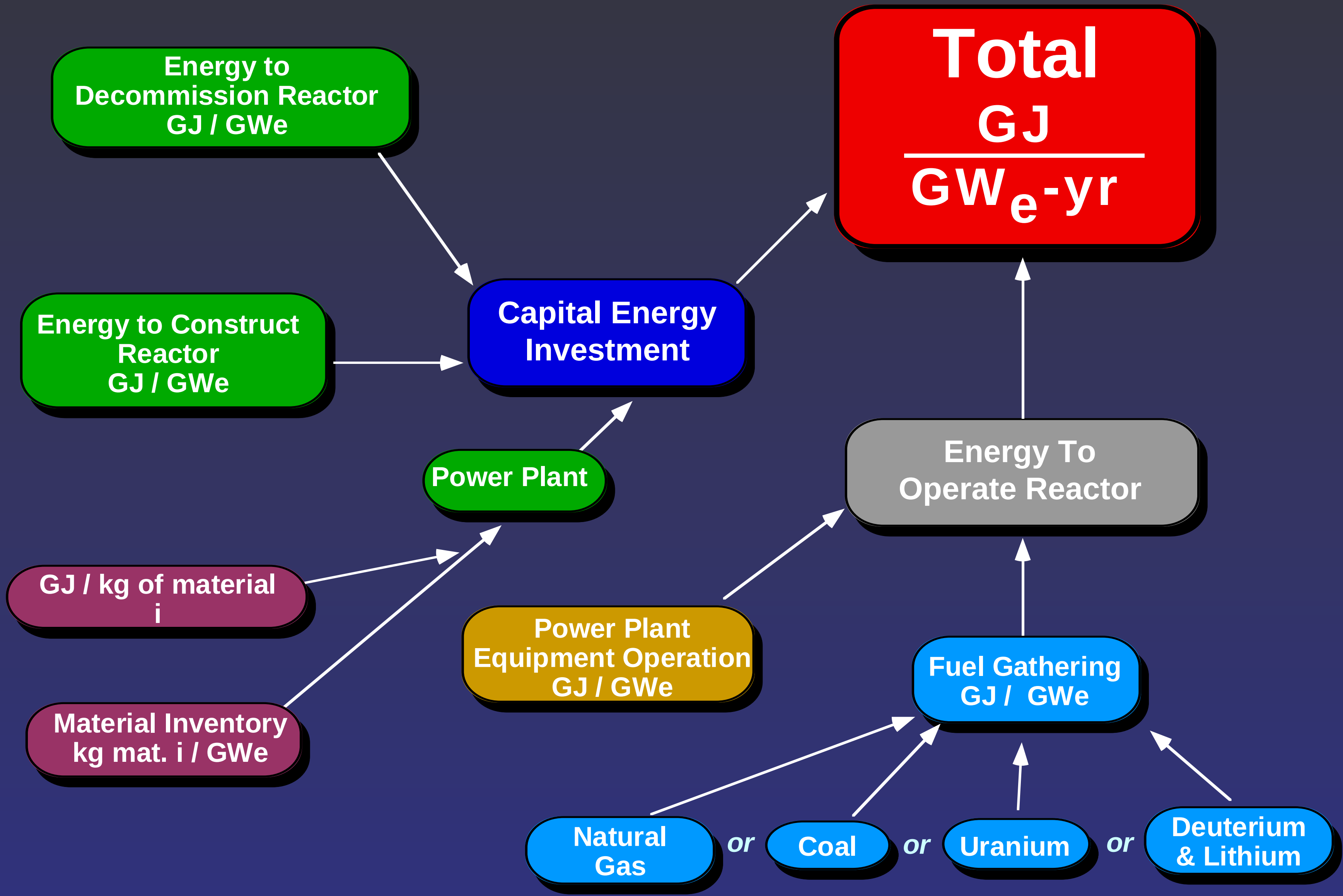
- **Calculate the Greenhouse Gas Emissions Associated With Coal, Natural Gas, Fission, Wind, and DT Fusion Electrical Power Plants**

  Include all fossil input to fuel and structural materials procurement, operations, and decommissioning

- **Assess How the U.S. Electrical Generating System Can "Do Its Share" to Meet the 1997 Kyoto Limits**

  Consider the 1990 minus 7% case

The Energy Investment in a Power Plant is Comprised of Many Components



Calculation of Energy Payback Ratio (EPR)

$$EPR = \frac{E_{n,L}}{\left(E_{mat,L} + E_{con,L} + E_{op,L} + E_{dec,L}\right)}$$

where $E_{n,L}$ = the net electrical energy produced over a given plant lifetime, L.

$E_{mat,L}$ = total energy invested in materials used over a plant lifetime L.

$E_{con,L}$ = total energy invested in construction for a plant with lifetime L.

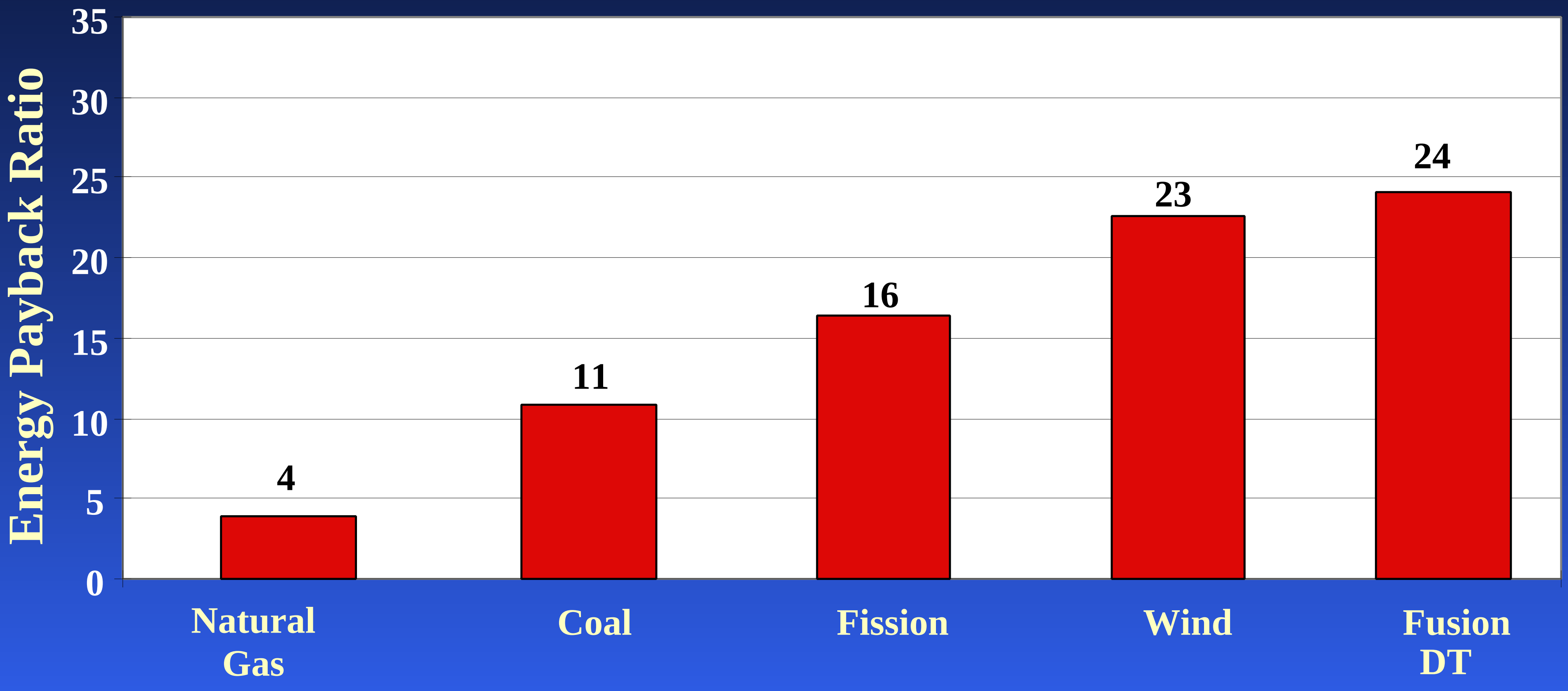
$E_{op,L}$ = total energy invested in operating the plant over the lifetime L.

$E_{dec,L}$ = total energy invested in decommissioning a plant after it has operated for a lifetime L.

Summary of the Normalized Energy Investments Made in Electrical Generating Plants- ($TJ_{th}/GW_{e}y$)

Process	Coal	Natural Gas	Wind	Fission	DT Fusion
Fuel Related	2,318	6,932	0	1,299	30
Plant Materials &	147	147	875	195	927
Operation	440	418	489	239	318
Decommissioning	20	11	50	191	51
Total	2,925	7,508	1,414	1,923	1,326
Energy Payback	**11**	**4**	**23**	**16**	**24**

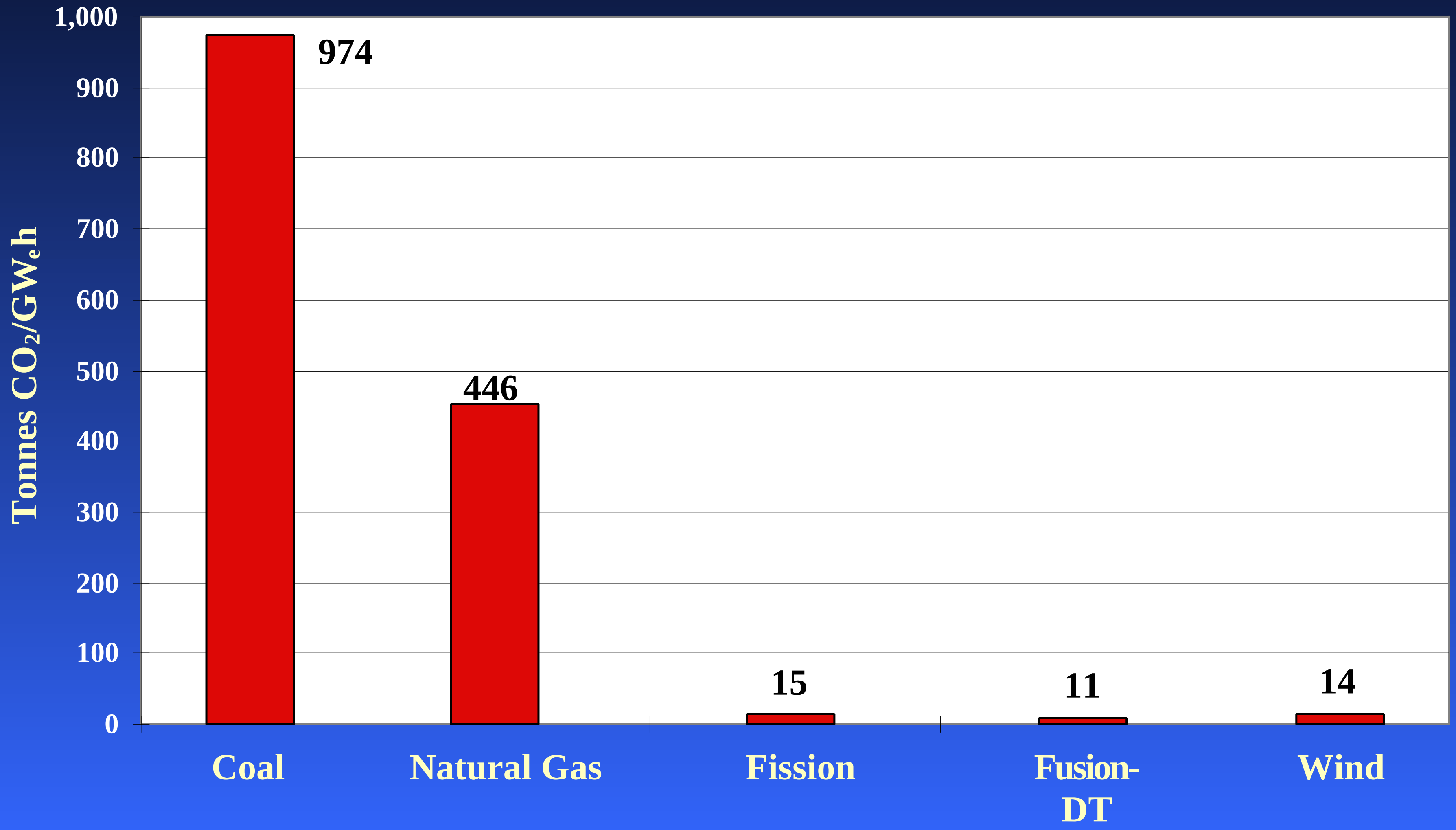
The Energy Payback Ratio Varies by a Factor of Nearly 6 Between Natural Gas and Fusion Power



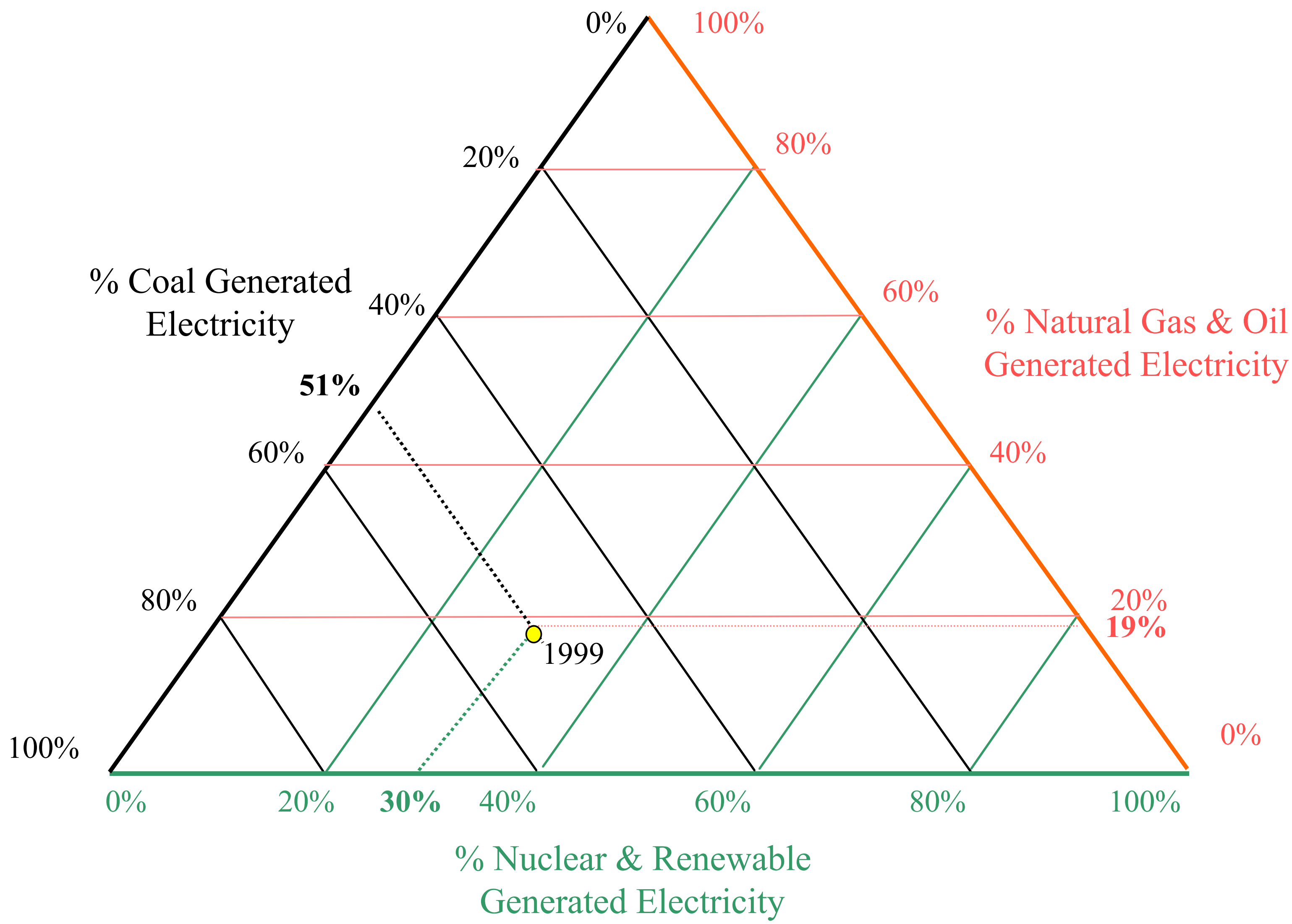
Summary of the Normalized Greenhouse Gas Emission Factors (Tonnes CO_2/GW_eh)

Process	Coal	Natural Gas	Wind	Fission	DT Fusion
Fuel Related	17	76	0	10	0.2
Plant Materials &	1	1	10	2	8
Operation	956	369	4	2	2
Decommissioning	0.2	0.1	0.4	1	0.4
Total	**974**	**446**	**14**	**15**	**11**

Relative to the CO_2 Emissions of Coal, Those from the Nuclear and Wind Technologies are Low, But Not Zero



U.S. Electricity Generation Contribution



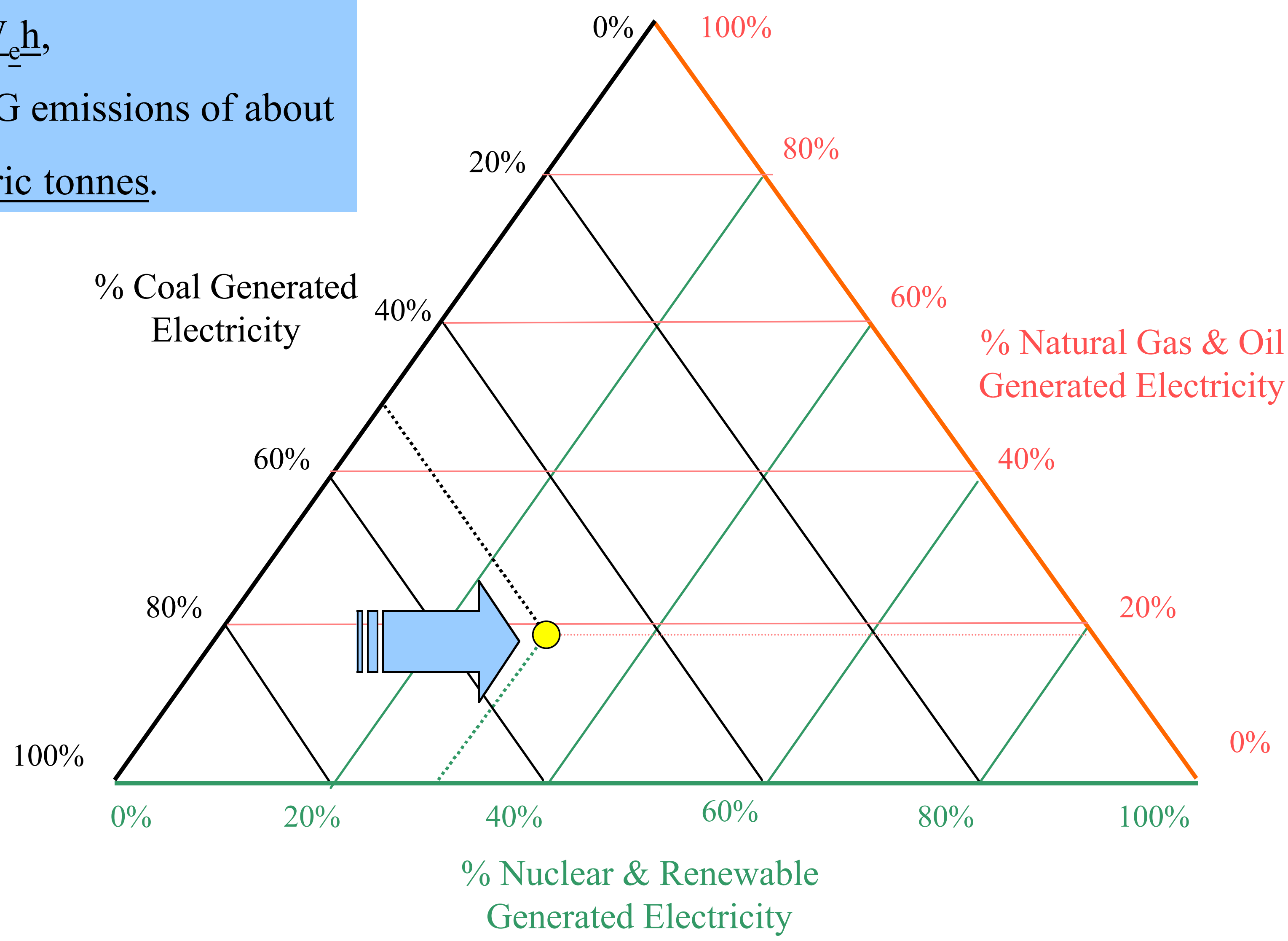
Relative CO_2-equivalent Emissions

Using this mixture of technologies, 1998 U.S. Electricity Production of

3.6 million GW_eh,

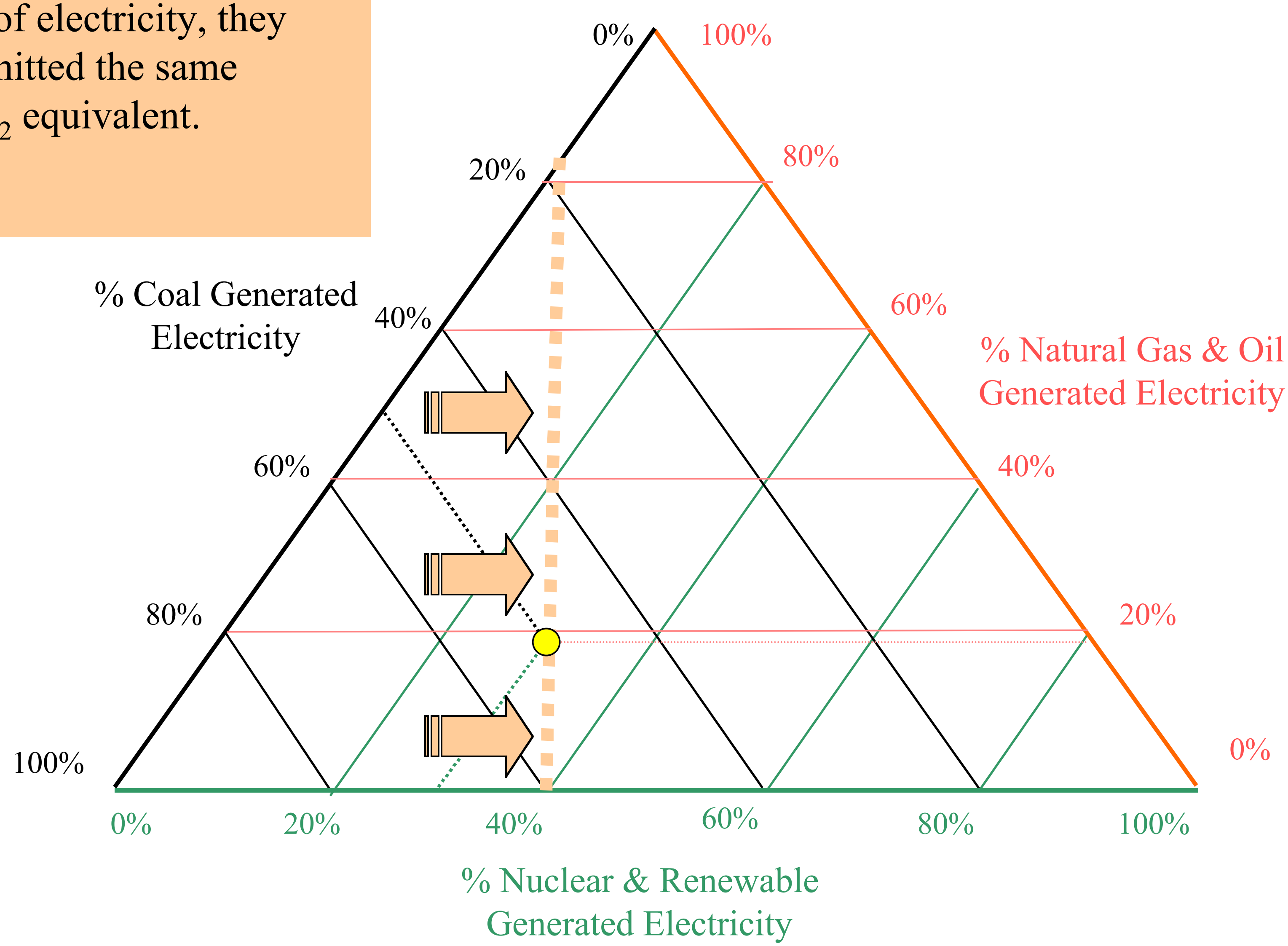
resulted in GHG emissions of about

2.2 billion metric tonnes.



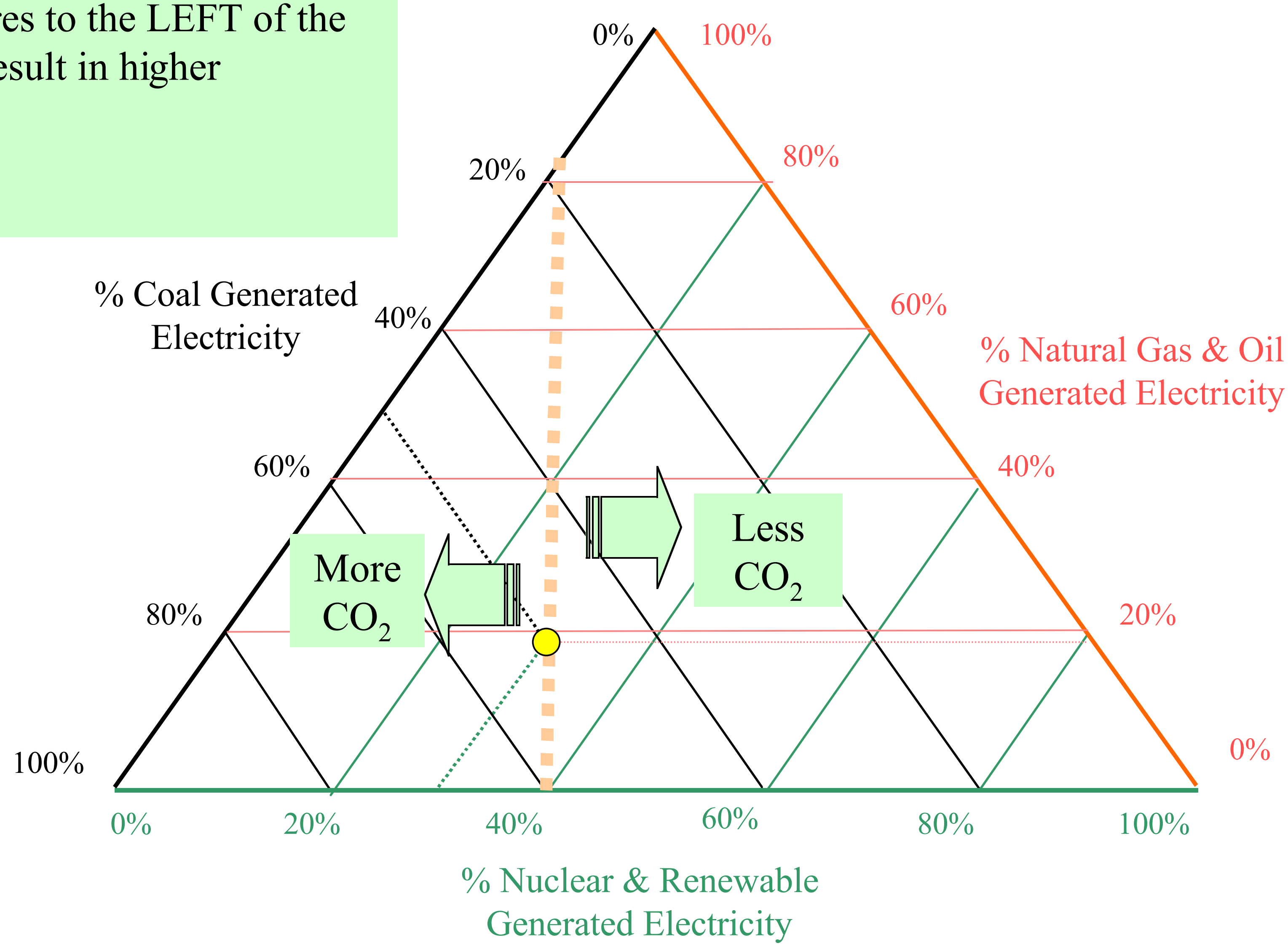
Relative CO_2-equivalent Emissions

If the following “mixtures” could have been used to the produce the same amount of electricity, they would have emitted the same amount of CO_2 equivalent.



Relative CO_2-equivalent Emissions

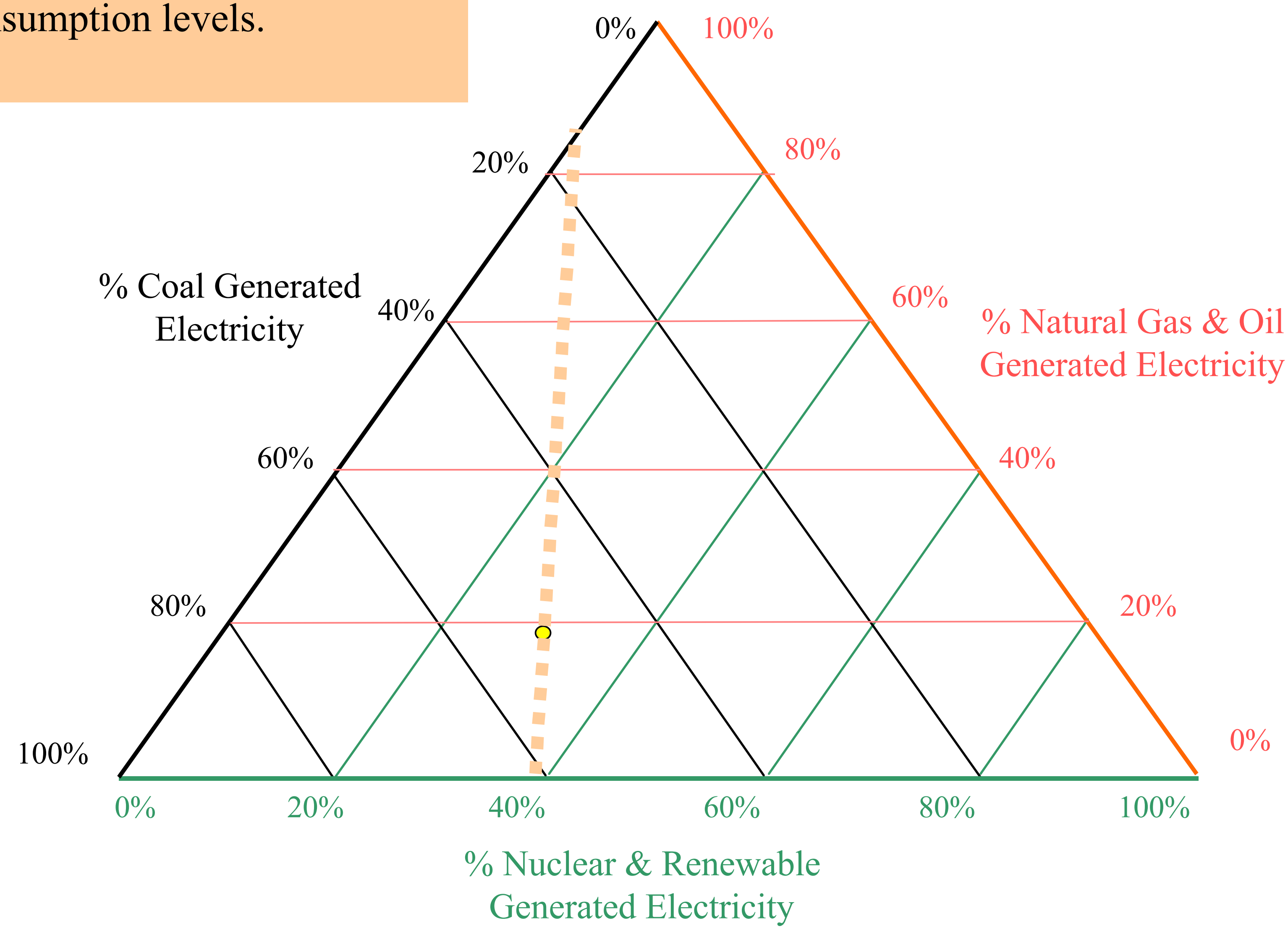
Mixtures to the RIGHT of the line, would result in fewer emissions, while mixtures to the LEFT of the line would result in higher emissions.



Relative CO_2-equivalent Emissions

Electricity Production (10^6 GWeh)	CO_2 Emission (10^9 tonnes)
3.6	2.2

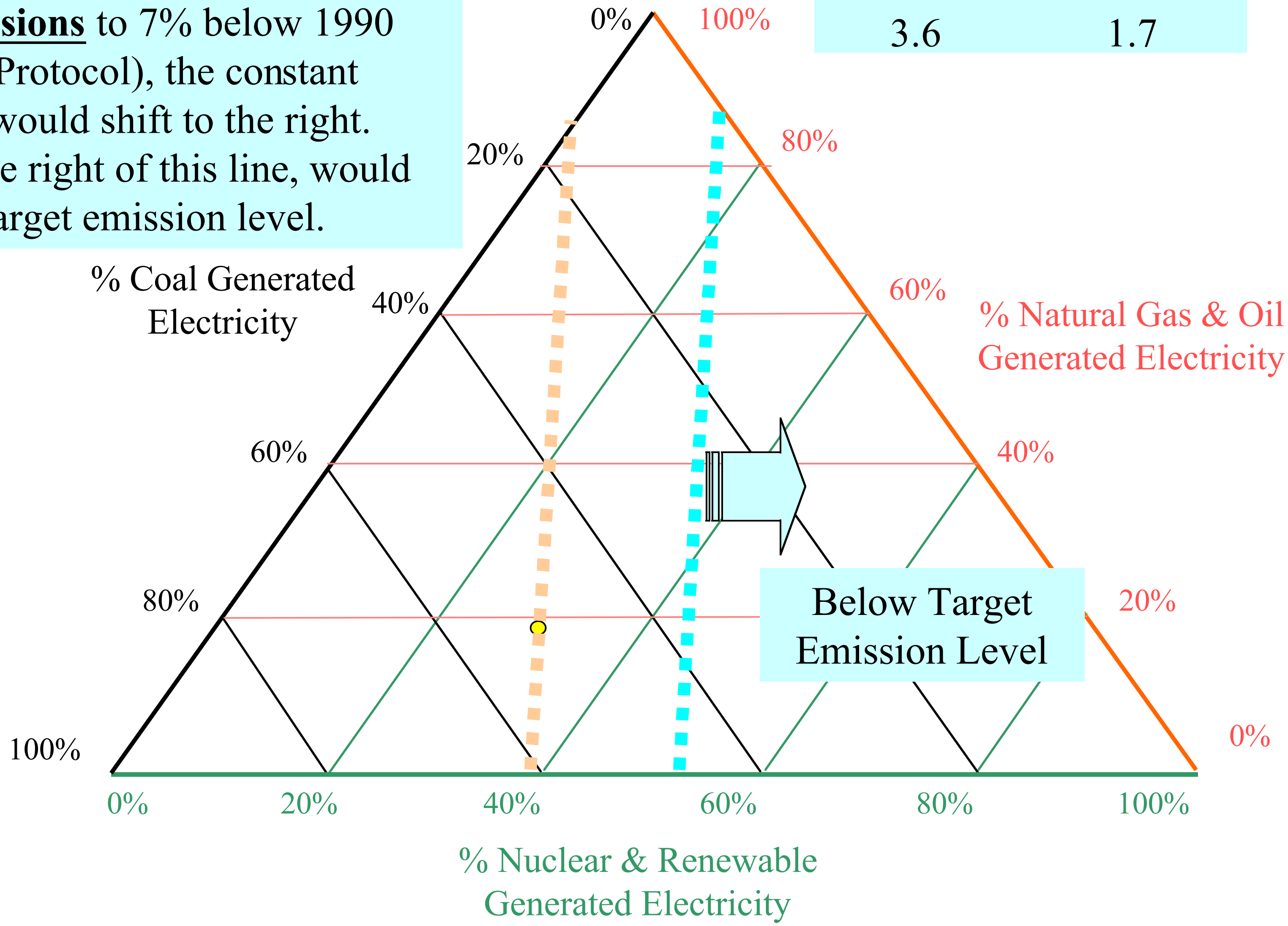
As shown previously, this line represents a constant emission line for the current electricity consumption levels.



Relative CO_2-equivalent Emissions

Electricity Production (10^6 GWeh)	CO_2 Emission (10^9 tonnes)
3.6	2.2
3.6	1.7

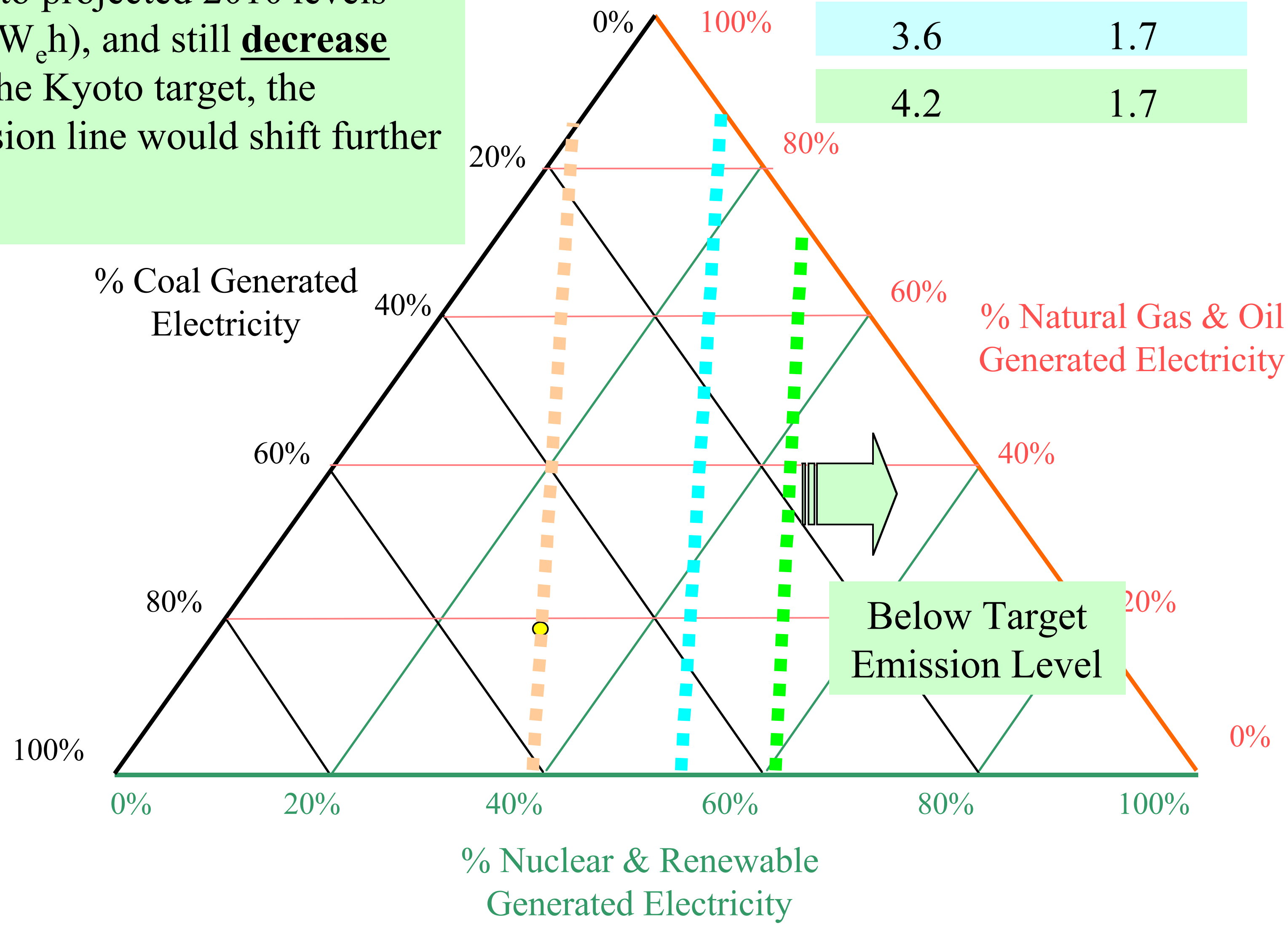
However, if we want to **maintain the same electricity consumption**, but **decrease emissions** to 7% below 1990 levels (Kyoto Protocol), the constant emission line would shift to the right. Anything to the right of this line, would be below the target emission level.



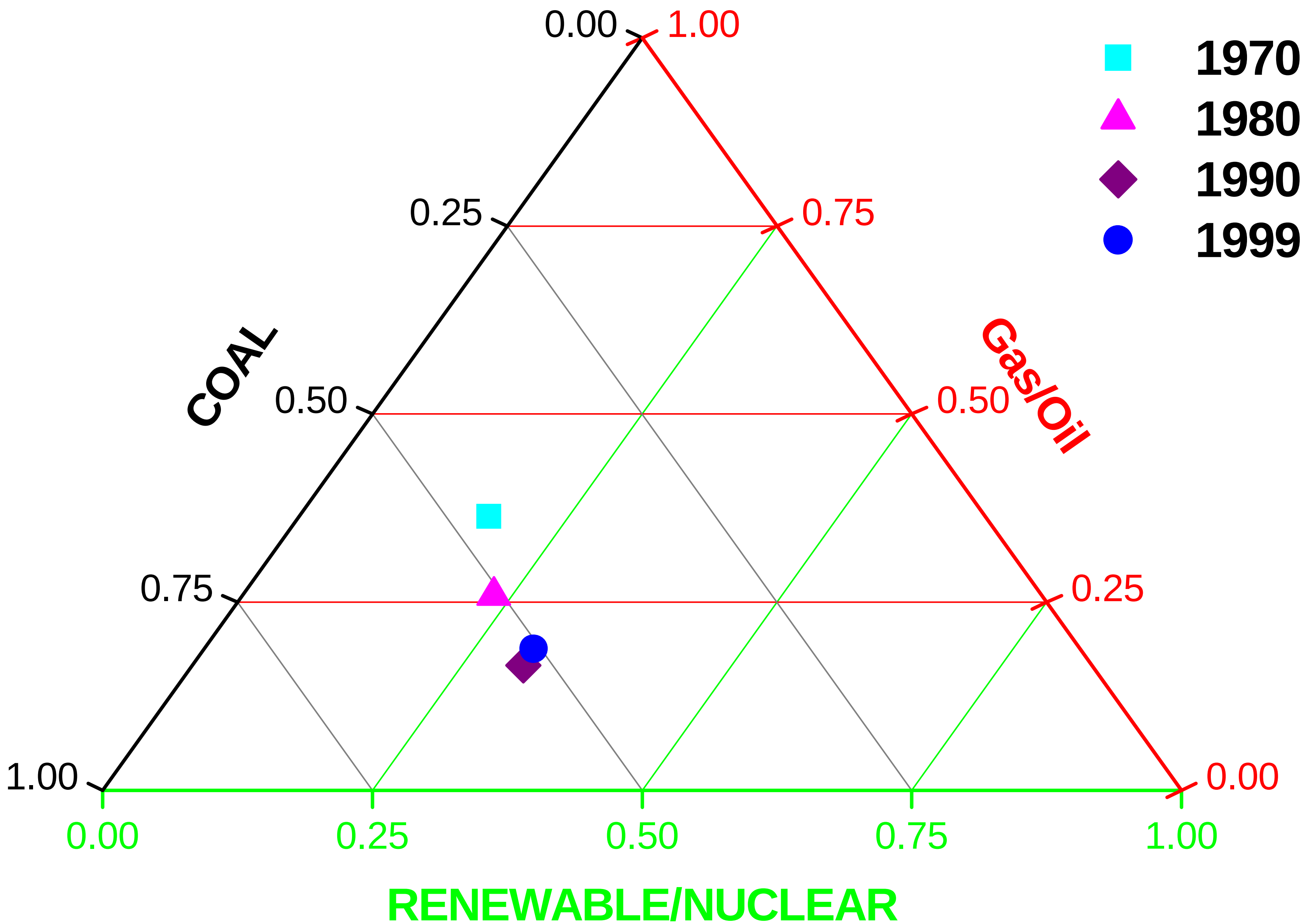
Relative CO_2-equivalent Emissions

If we wanted to **increase electricity consumption** to projected 2010 levels (4.2 million GW_eh), and still **decrease emissions** to the Kyoto target, the constant emission line would shift further to the right.

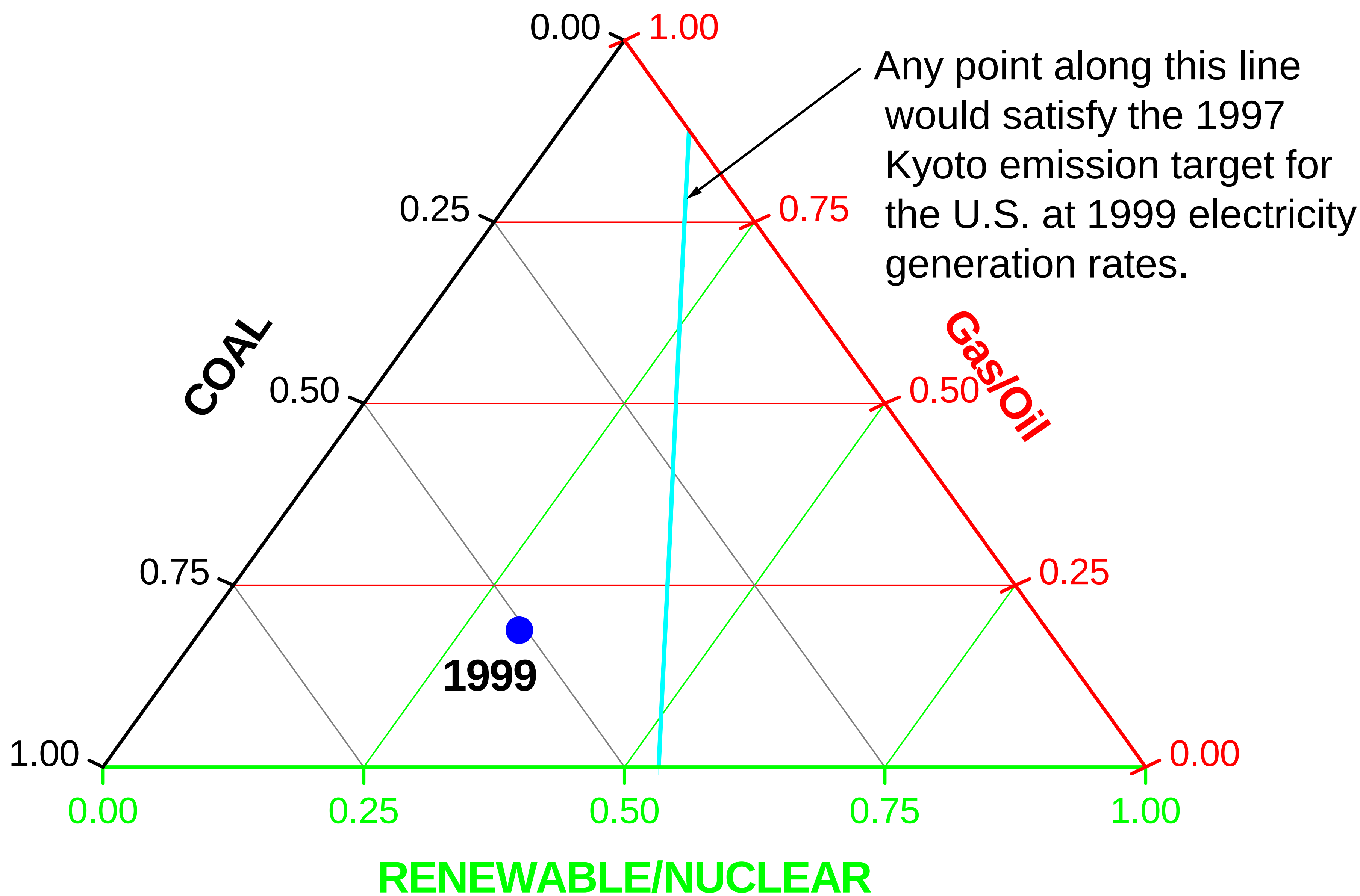
Electricity Production (10^6 GWeh)	CO_2 Emission (10^9 tonnes)
3.6	2.2
3.6	1.7
4.2	1.7



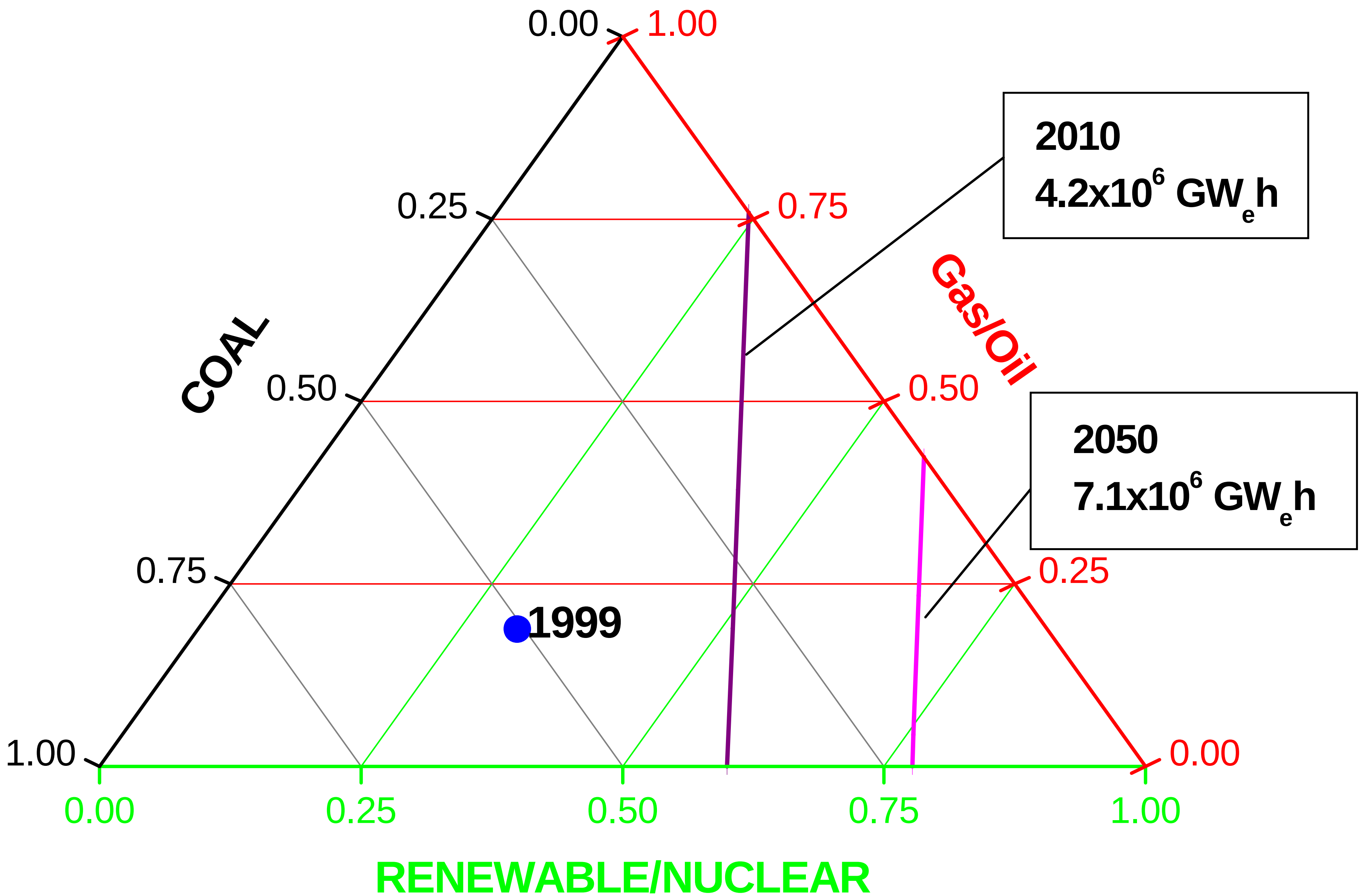
20 Years of Increased Reliance on Coal and Nuclear Power Sources Stalled in the 1990's



There Would Have to be a Major Shift Toward Nuclear/Renewable and Natural Gas Technologies, In Order to Immediately Comply With the 1997 Kyoto Emission Target for the U.S.



An Increasing Reliance on Nuclear and Renewable Sources is Required, if Proposed Kyoto Emission Targets Were Satisfied at Anticipated Future Electricity Growth Rates (1.3%).



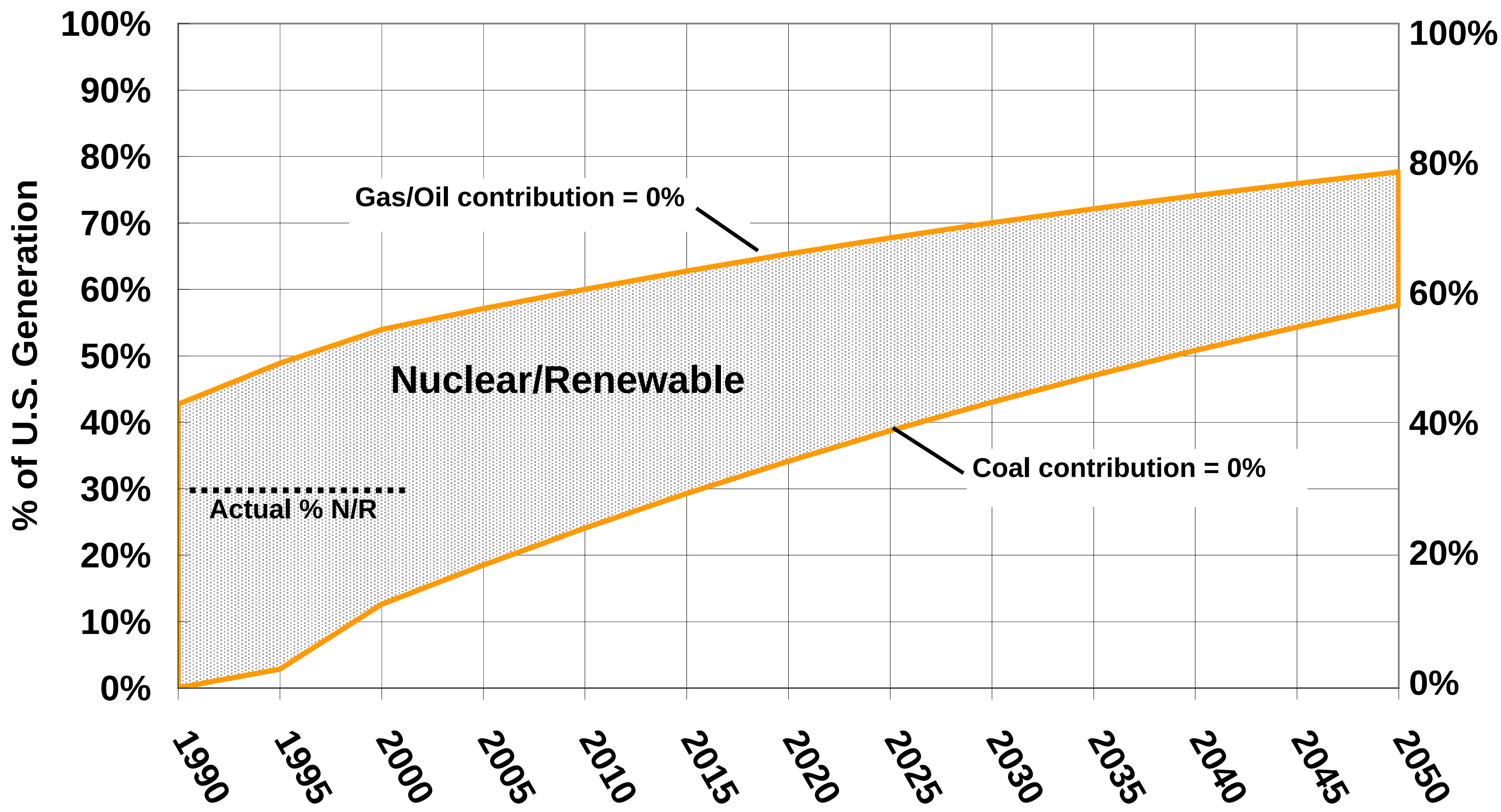
What If the U.S. Chooses to Comply With the 1997 Kyoto Greenhouse Gas Emission Targets?

- **What is the Requirement for Low Greenhouse Gas Emitting Power Generating Plants in the 2000-2050 Period?**

Assume: 1.3% annual growth rate for electricity (conservative, EIA)

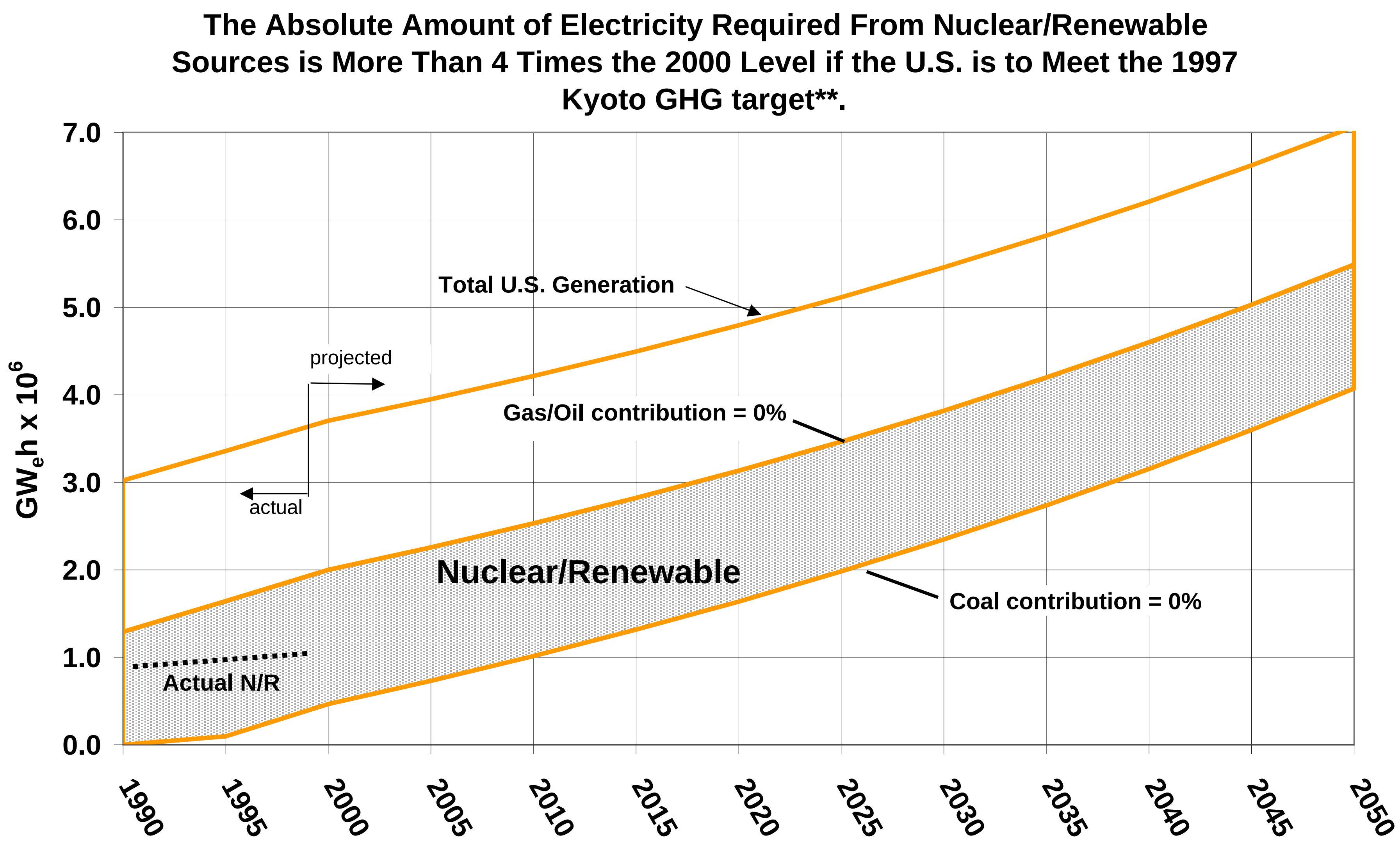
Assume: The electricity generating sector will reduce emissions to 1990 level minus 7%

The Required Nuclear/Renewable Contributions to U.S. Electricity Generation* That Would Meet the 1997 Kyoto GHG Target** for the U.S. Would Have to More Than Double From the Level in 2000.



*Future Electrical Growth assumed 1.3%

* *Target assumes that the U.S. electric industry meets its proportion of the Kyoto commitment by reducing emissions to 7% below its 1990 baseline.



*Future Electrical Growth assumed 1.3%

* *Target assumes that the U.S. electric industry meets its proportion of the Kyoto commitment by reducing emissions to 7% below its 1990 baseline.

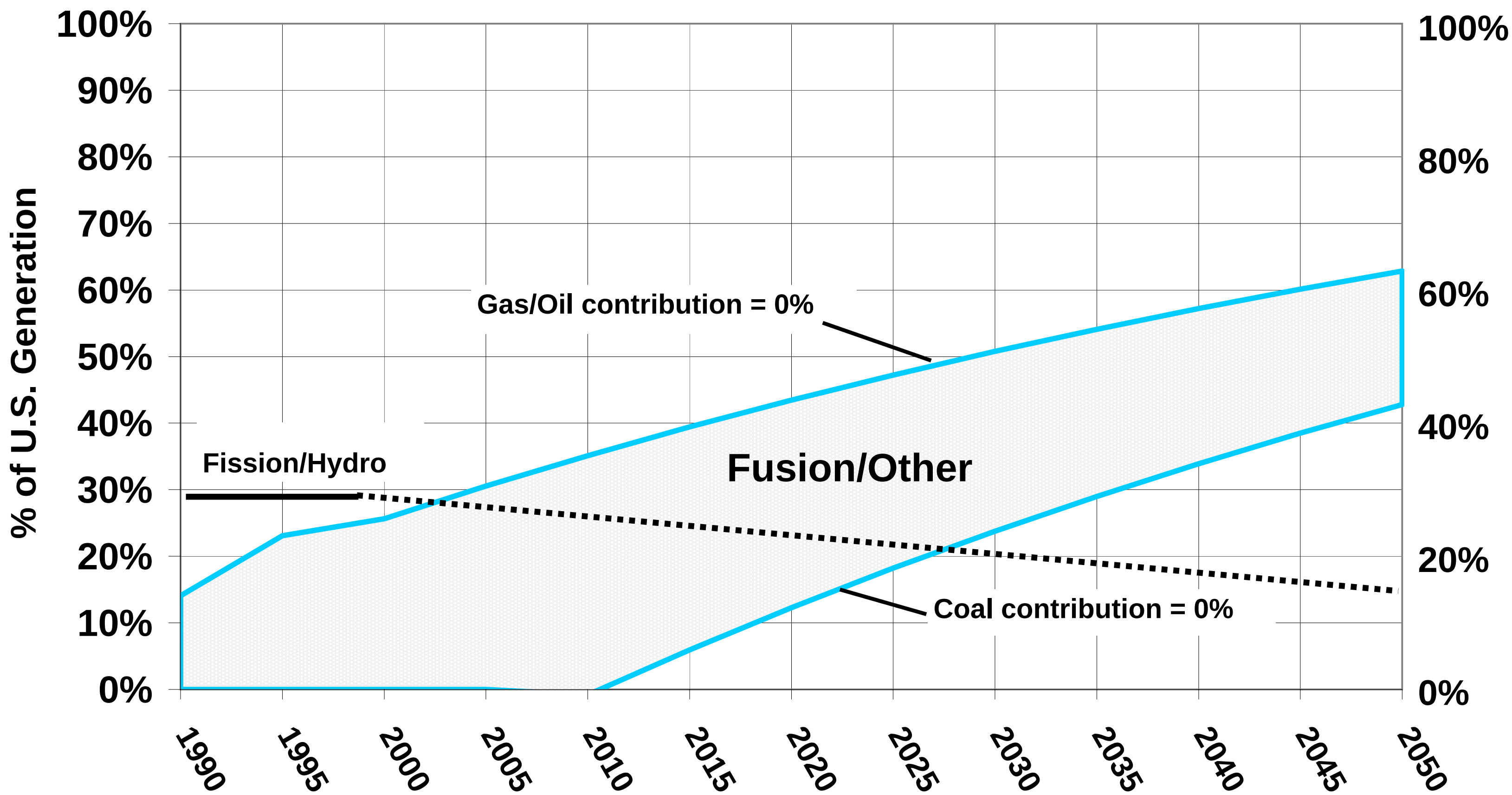
What If the Level of Electricity from Fission and Hydro Sources Remain Constant in the 2000-2050 Time Period?

- **The electricity generated from other low GHG emitting sources (wind, solar, fusion, etc.) must increase dramatically after 2010.**

Assume: Net amount of electricity from fission and hydro is not changed from 2000 level

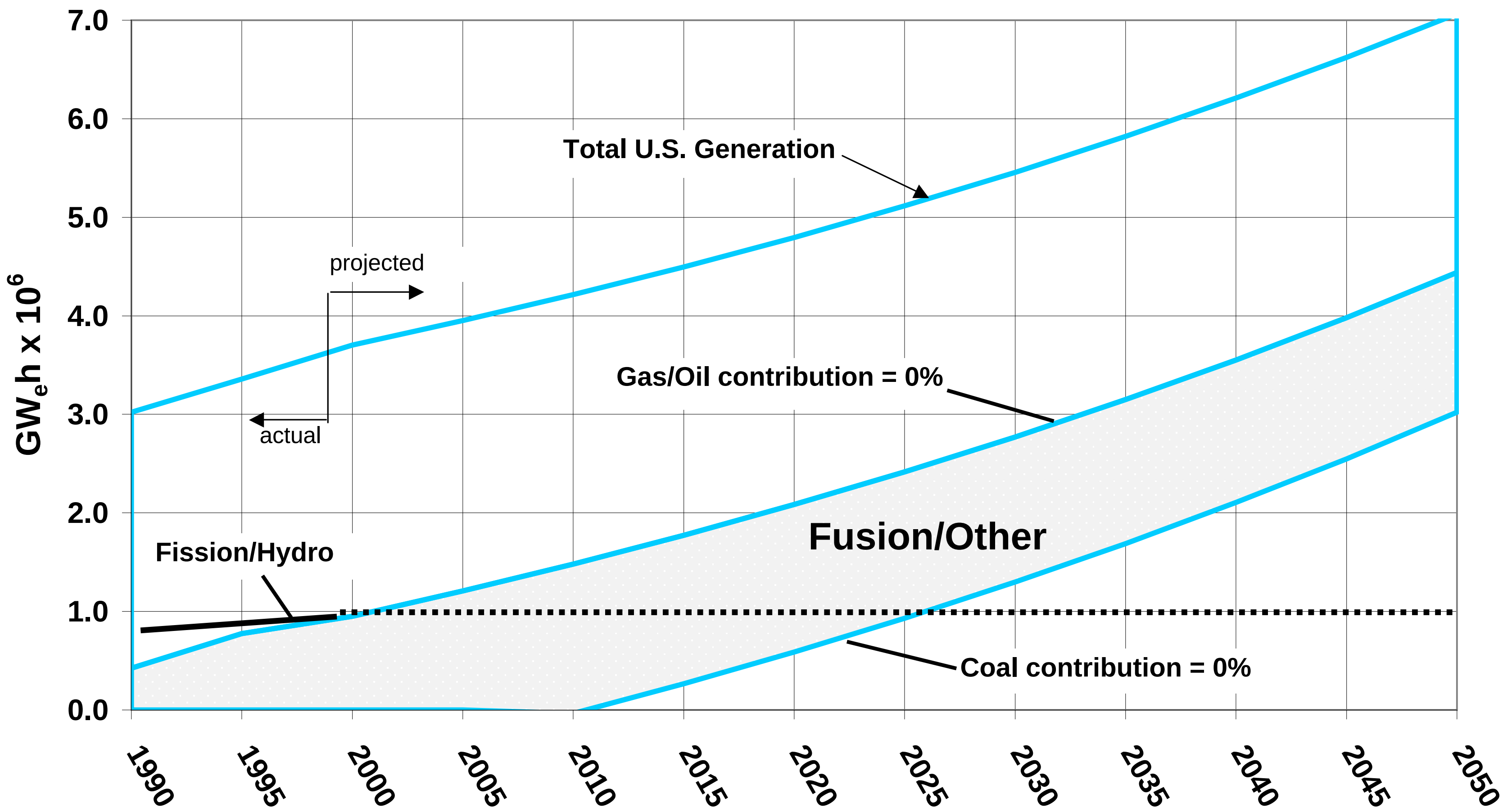
Assume: New fission and hydro replace retired fission and hydro in the 2000-2050 period

If Fission and Hydro Sources are Kept Constant, Other Sources of Low GHG Emitting Power Plants Are Needed No Later Than 2010 if the U.S. is to Meet the 1997 Kyoto GHG Target.



* Implies potential for any nuclear or renewable technology other than fission or hydroelectricity.
** Future Electrical Growth assumed 1.3%
* ** Target assumes that the U.S. electric industry meets its proportion of the Kyoto commitment by reducing emissions to 7% below its 1990 baseline.

In Order to Meet the 1997 Kyoto Target for the U.S., the Absolute Amount of Electricity From Low GHG Emitting Technologies Will Have to Be Approximately 3 Times the Current Level by the Year 2050.



* Implies potential for any nuclear or renewable technology other than fission or hydroelectricity.
** Future Electrical Growth assumed 1.3%
* ** Target assumes that the U.S. electric industry meets its proportion of the Kyoto commitment by reducing emissions to 7% below its 1990 baseline.

Conclusions

- **The "birth to death" analysis of energy payback ratios (EPR's) for electrical generating plants reveals that DT fusion plants have one of the highest EPR values at 24.**

  This compares to 4-23 for conventional (natural gas, coal, fission, and wind) power stations.

- **The greenhouse gas emission rate per $GW_e h$ for DT fusion plants is low at 11 tonnes $CO_2/GW_e h$.**

  This compares favorably to 14-15 for wind and fission respectively and 446 to 974 for natural gas and coal respectively.

Conclusions (cont.)

- **Adherence to the 1997 Kyoto agreements *(1990 minus 7% emission rates and 1.3%/y demand growth rates)* will require quadrupling the nuclear/renewable capacity in United States over the next 50 years (not considering replacements).**

Factoring in replacements, quadrupling requires ≈600 new 1000 MW_e low-greenhouse gas emitting electricity-generating power plants in the U. S. over the next 50 years.