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”

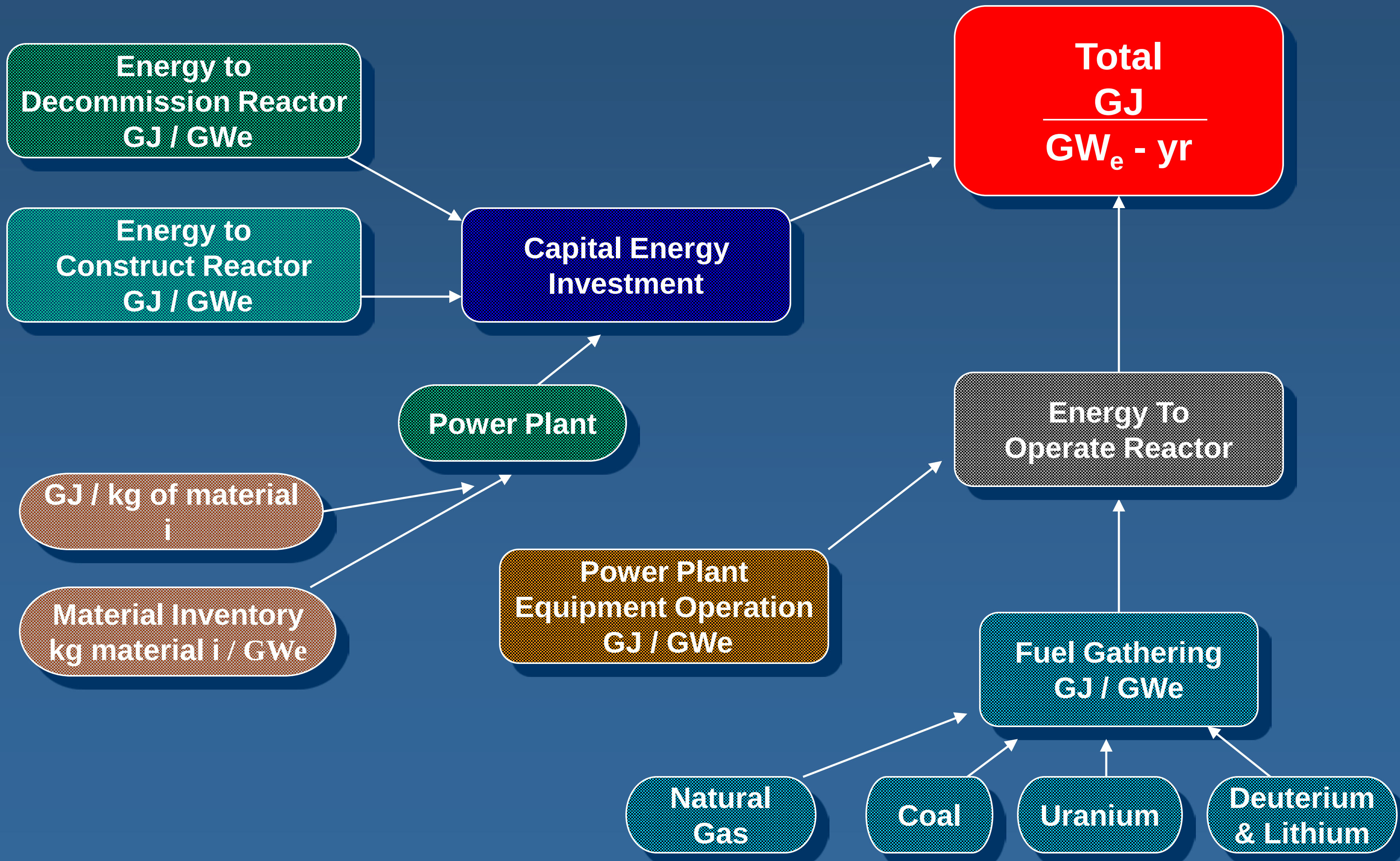
- **Calculate the Greenhouse Gas Emissions Associated With Coal, Natural Gas, Fission, Wind, and DT Fusion Electrical Power Plants**

  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)

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

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

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

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

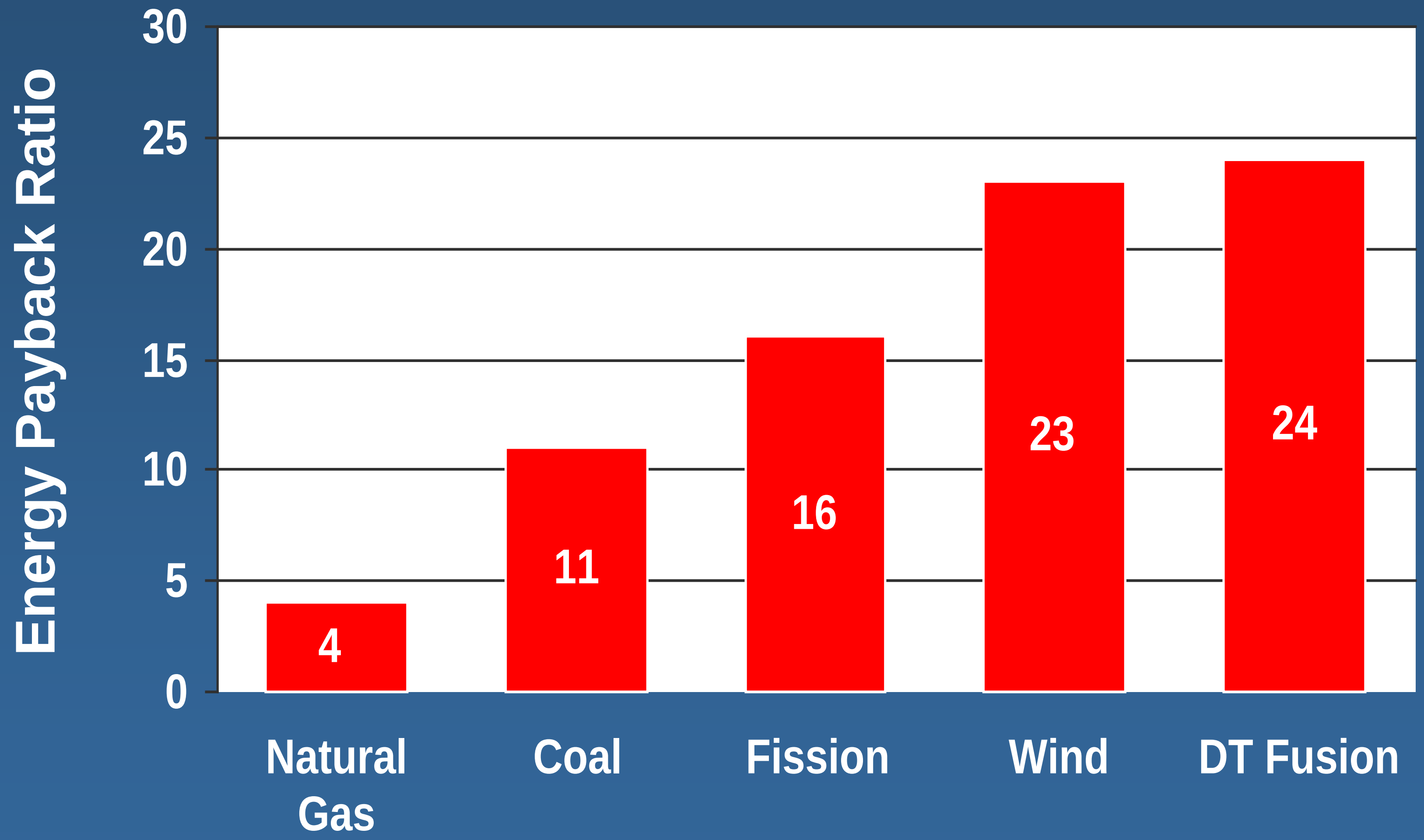
$E_{op,L}$ = total energy invested in operating the plant over the lifetime L.

$E_{dec,L}$ = 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	Natural Gas	Coal	Fission	Wind	DT Fusion
Fuel Related	7,327	2,318	1,299	0	30
Plant Materials & Construction	90	147	195	875	927
Operation	323	440	239	489	318
Decommissioning	3	20	191	50	51
Total	7,743	2,925	1,923	114	1,326

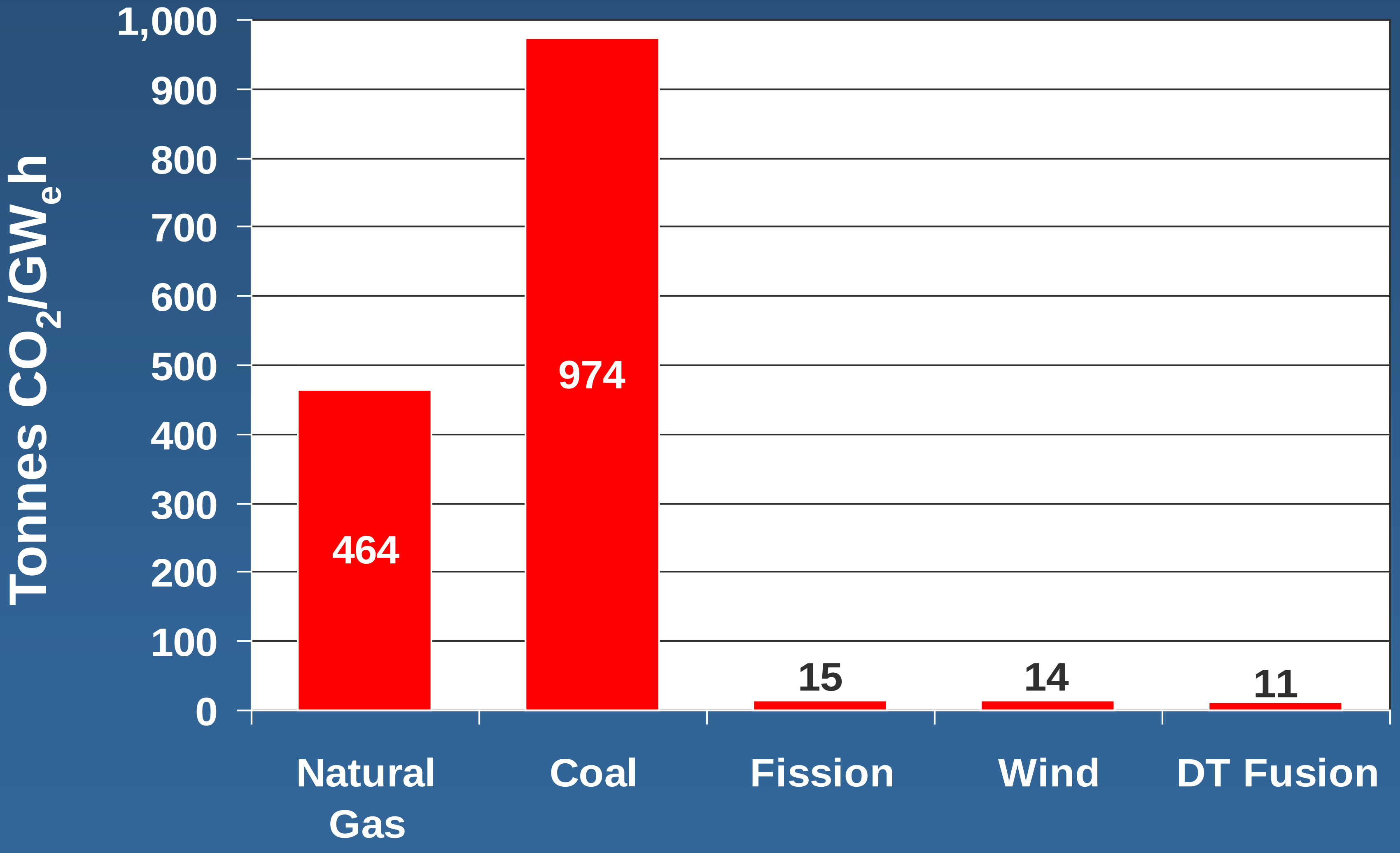
The Energy Payback Ratio Varies by a Factor of Nearly 6 Between Natural Gas and Fusion Power



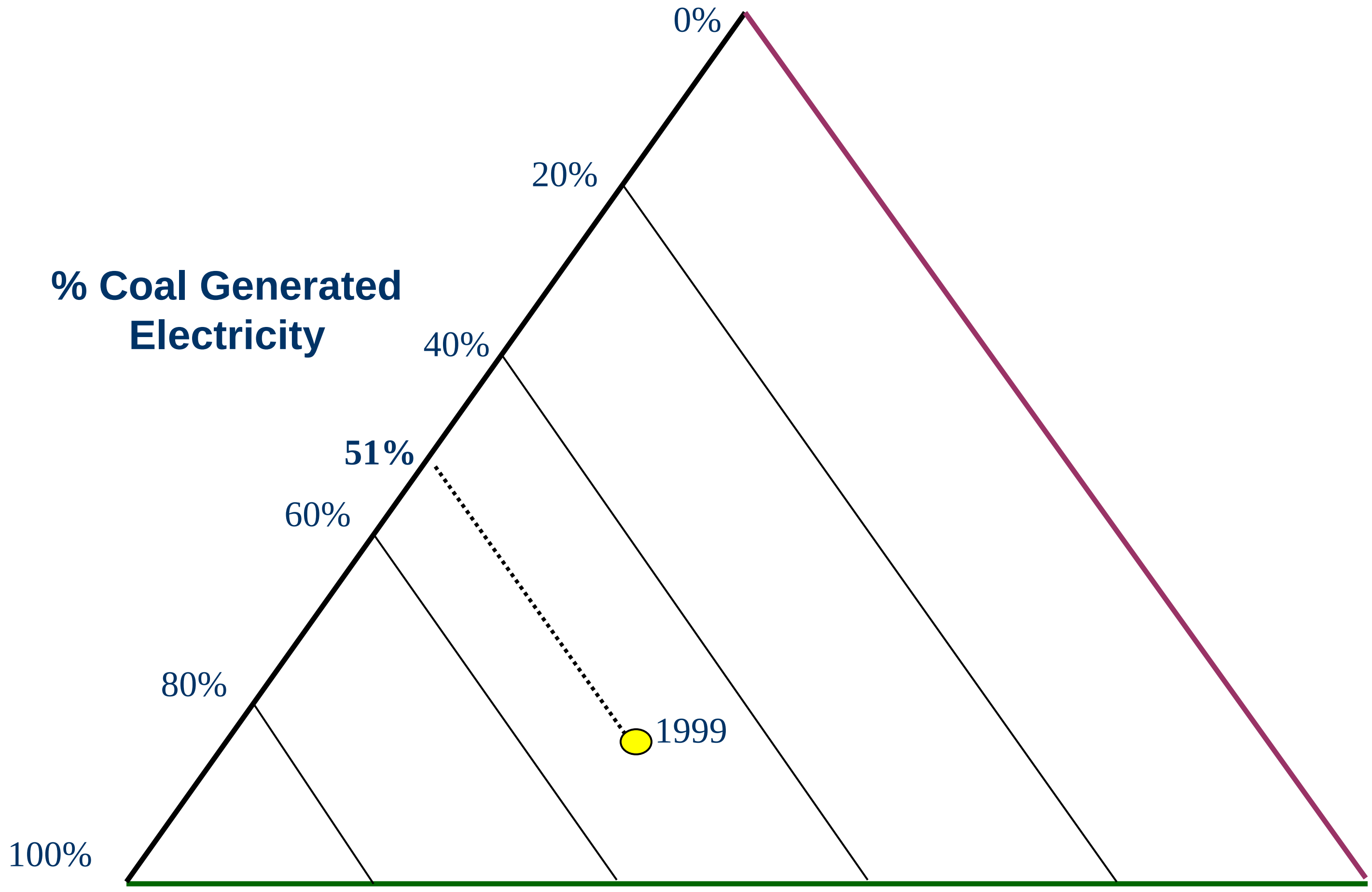
Summary of the Normalized Greenhouse Gas Emission Factors (Tonnes CO_2/GW_eh)

Process	Natural Gas	Coal	Fission	Wind	DT Fusion
Fuel Related	77	17	10	0	0.2
Plant Materials & Construction	2	1	2	10	8
Operation	385	956	2	4	2
Decommissioning	0.02	0.2	1.0	0.4	0.4
Total	**464**	**974**	**15**	**14**	**11**

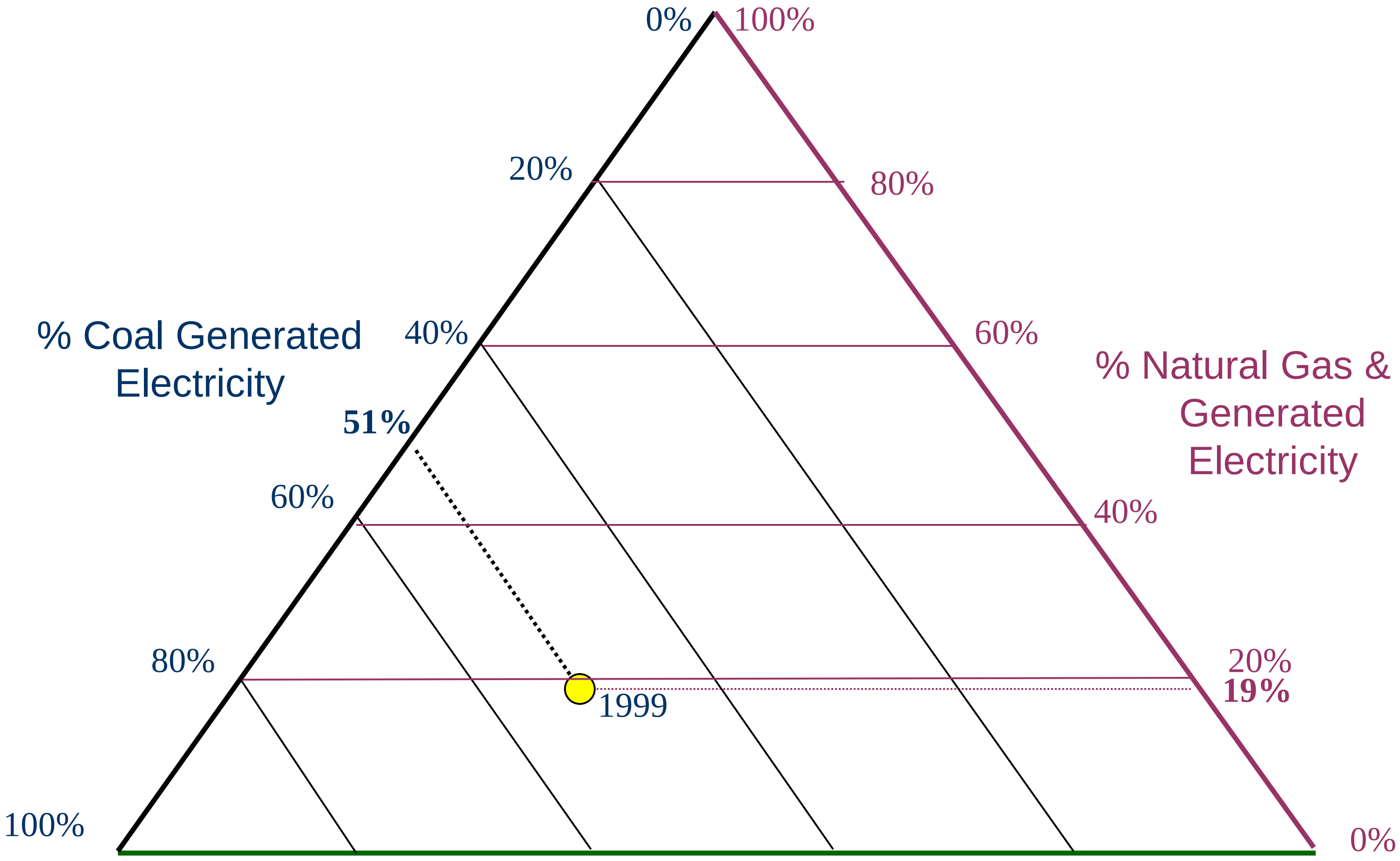
Relative to the CO_2 Emissions of Coal, Those from Nuclear and Wind Technologies are Low, But Not Zero



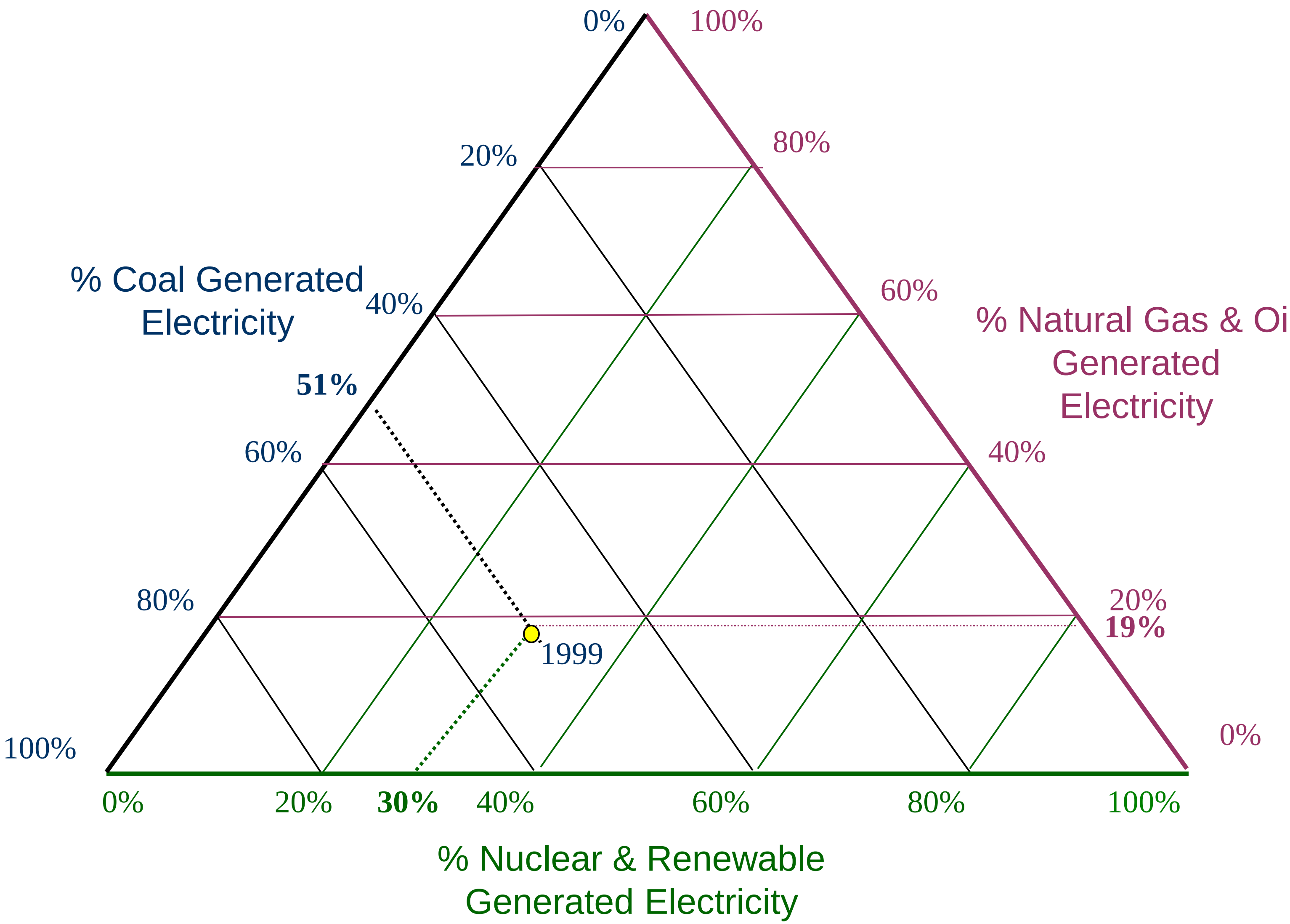
U.S. Electricity Generation-Fuel Contribution



U.S. Electricity Generation Contribution

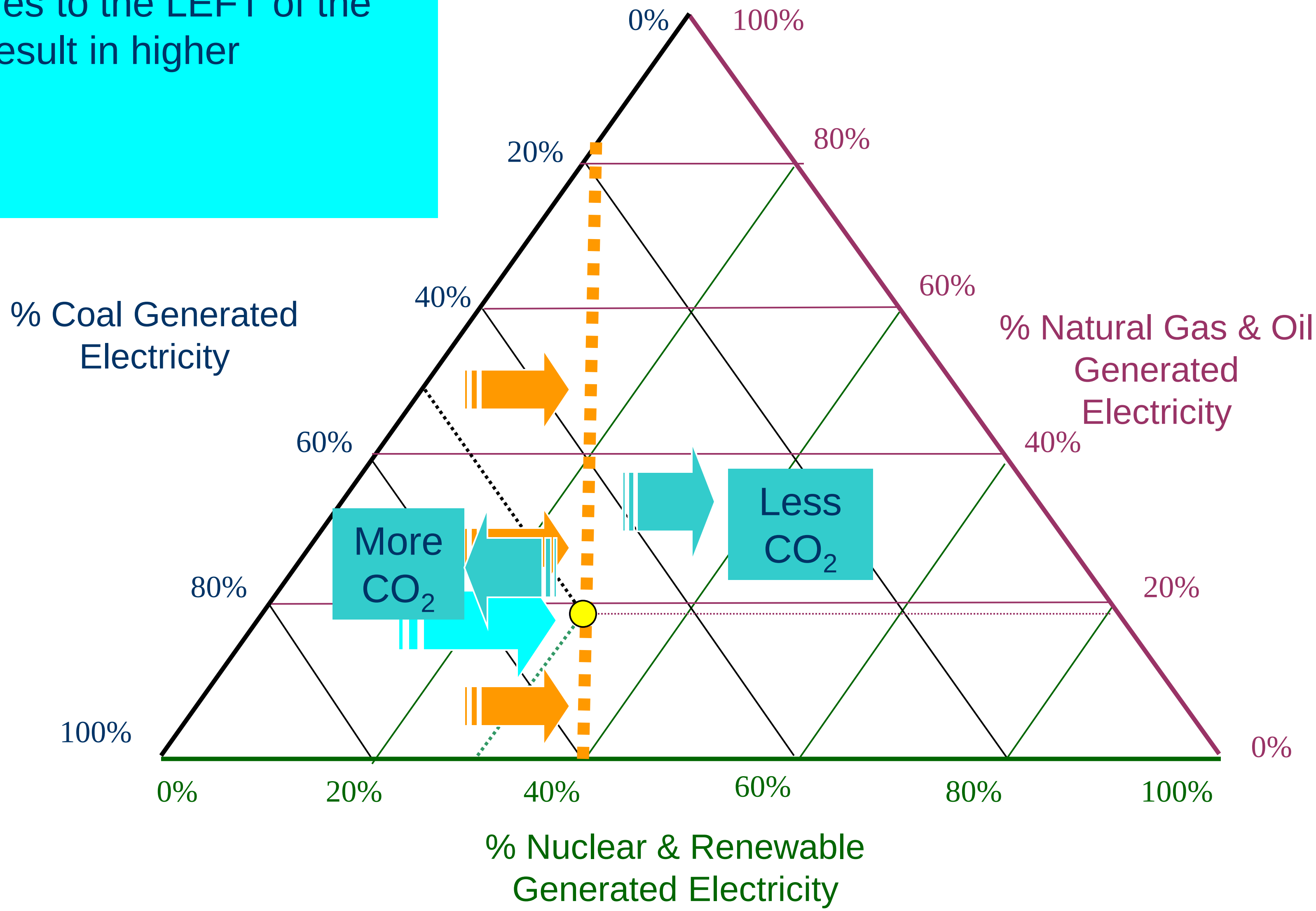


U.S. Electricity Generation Contribution



Relative CO_2-Equivalent Emissions

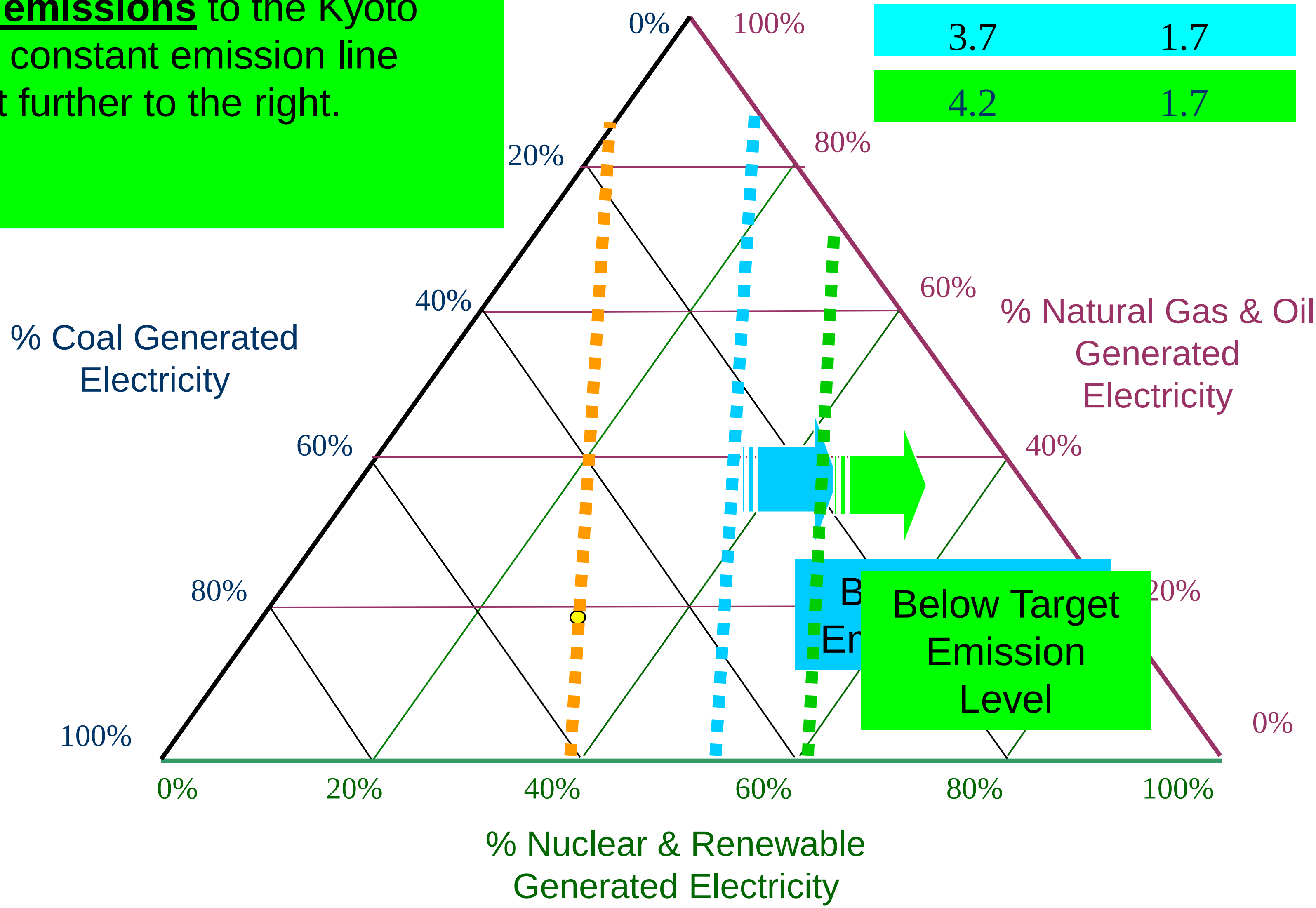
Mixtures to the RIGHT of the line, would result in fewer emissions, while mixtures to the LEFT of the line would result in higher emissions.



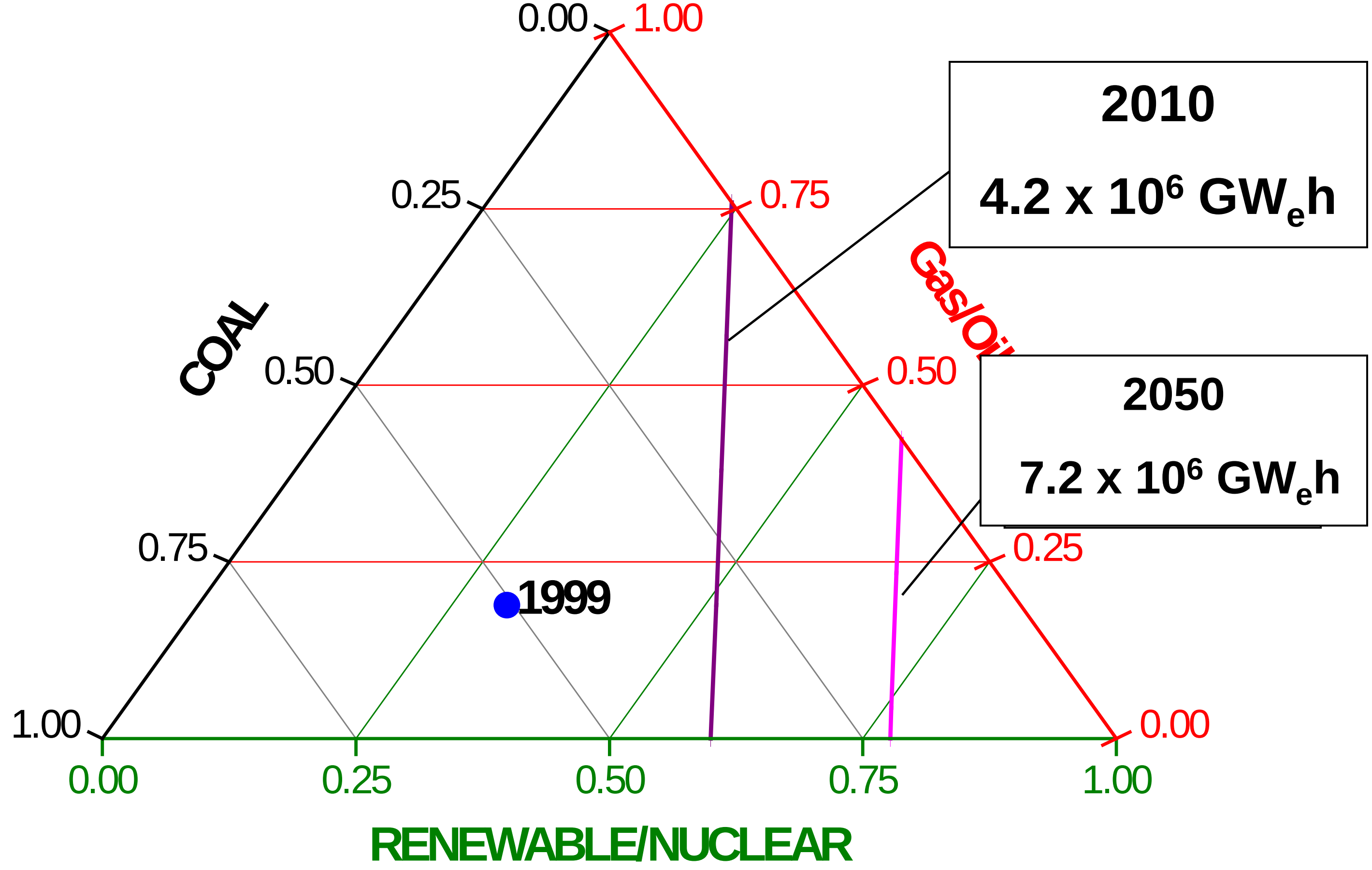
Relative CO_2-Equivalent Emissions

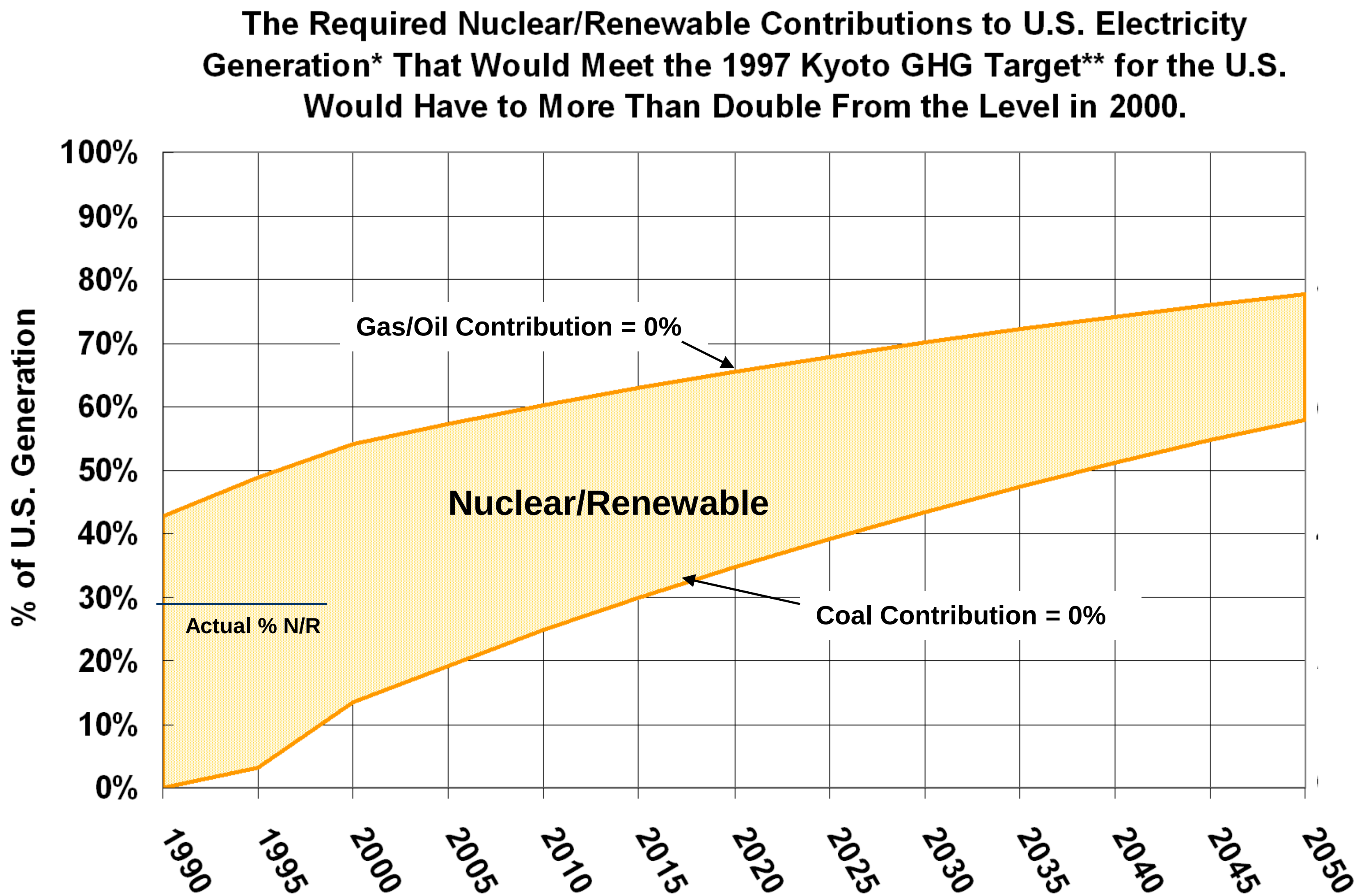
If we wanted to **increase electricity consumption** to projected 2010 levels (4.2 million GW_eh), and still **decrease emissions** to the Kyoto target, the constant emission line would shift further to the right.

Electricity Production (10^6 GWeh)	CO_2 Emission (10^9 tonnes)
3.7	2.2
3.7	1.7
4.2	1.7



An Increasing Reliance on Nuclear and Renewable Sources is Required, to Satisfy Proposed Kyoto Emission Targets at Anticipated U.S. Electricity Growth Rates (1.3%).

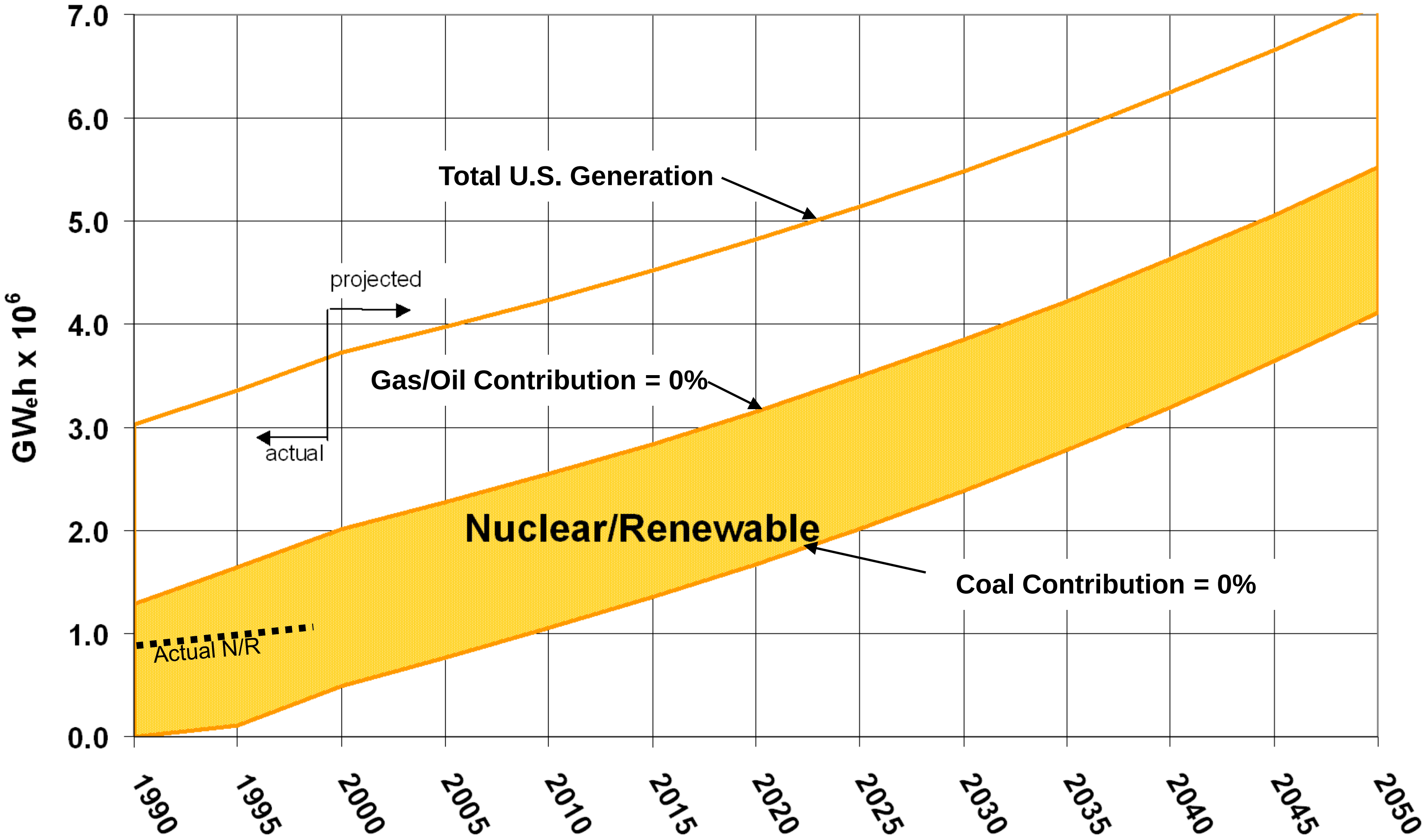




*Future Electrical Growth assumed 1.3%

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

The Absolute Amount of Electricity Required From Nuclear/Renewable Sources is More Than 4 Times the 2000 Level if the U.S. is to Meet the 1997 Kyoto GHG target**.



*Future Electrical Growth assumed 1.3%

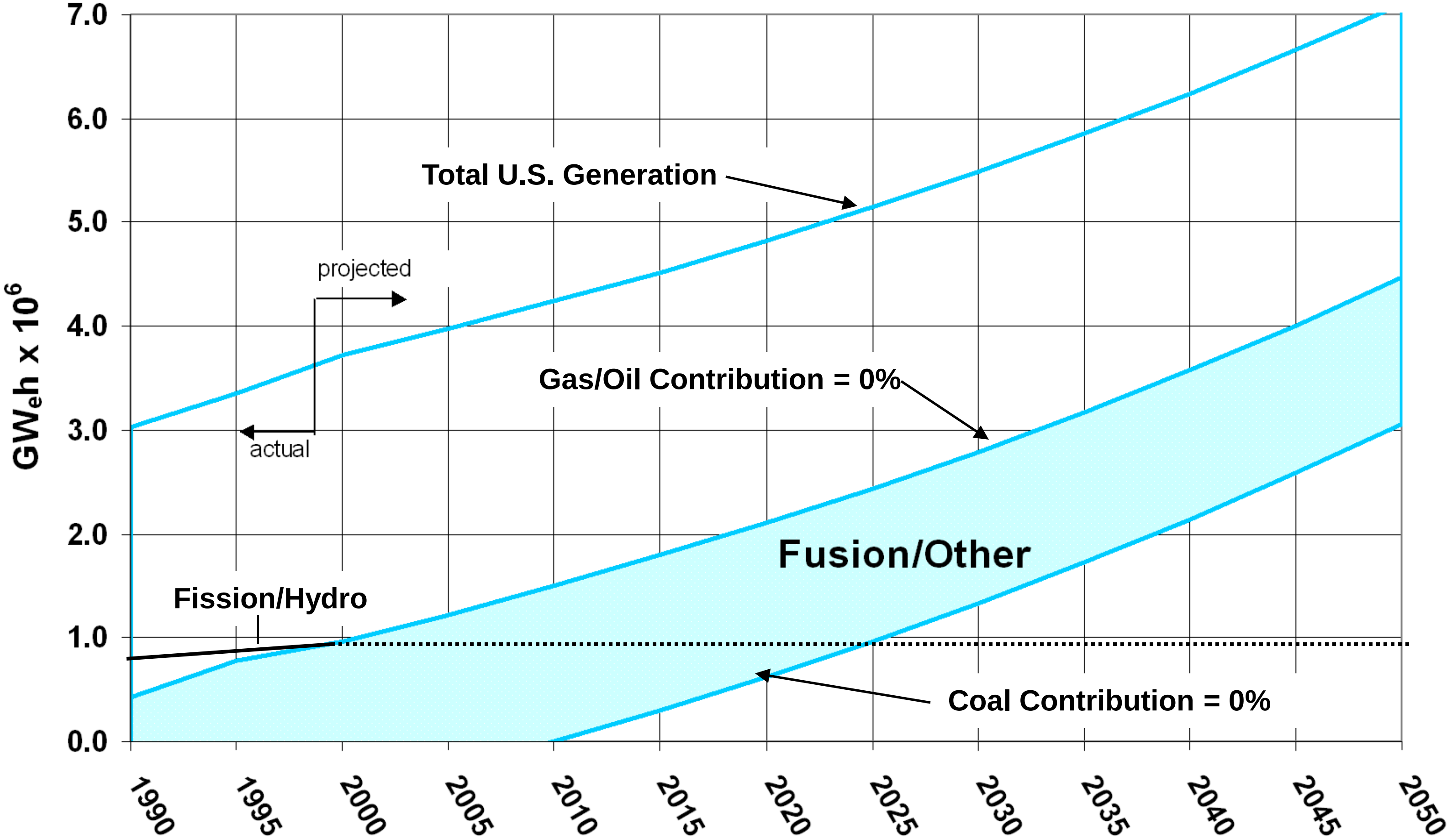
**Target assumes that the U.S. electric industry meets its proportion of the Kyoto commitment by reducing emissions to 7% below its 1990 baseline.

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

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

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

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_eh for DT fusion plants is low at 11 tonnes CO_2/Gw_eh.**

  This compares favorably to 14-15 for wind and fission respectively and 464 to 974 for natural gas and coal respectively.

Conclusions (cont.)

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

Factoring in replacements, quadrupling requires approximately 600 new 1,000 MW_e low-greenhouse gas emitting electricity-generating power plants in the U.S. over the next 50 years.

There are Two Methods to Measure Energy Input to Power Plants

Process Chain Analysis (PCA)

$\frac{\text{unit mass}}{GW_e \text{ or } GW_e y}$ X

Material	*GJ/tonne*
Aluminum	207
Concrete	1.4
Copper	131
Stainless Steel	53
Vanadium	3711
Rocket Fuel (LH_2)	460
Rocket Fuel (LO_x)	10
Titanium (for lunar mining equipment)	444

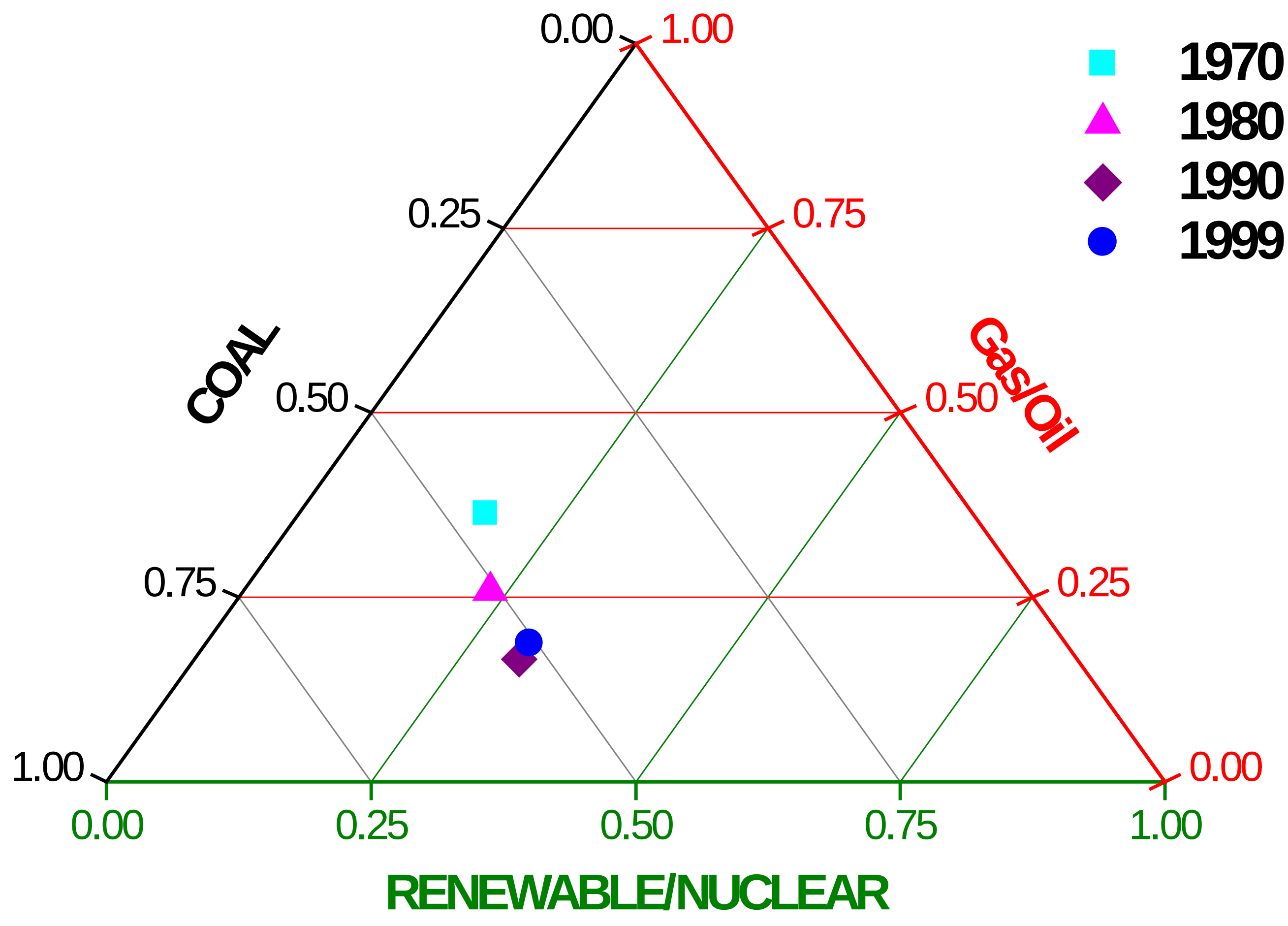
→ $\frac{GJ}{GW_e \text{ or } GW_e y}$

Input/Output (I/O)

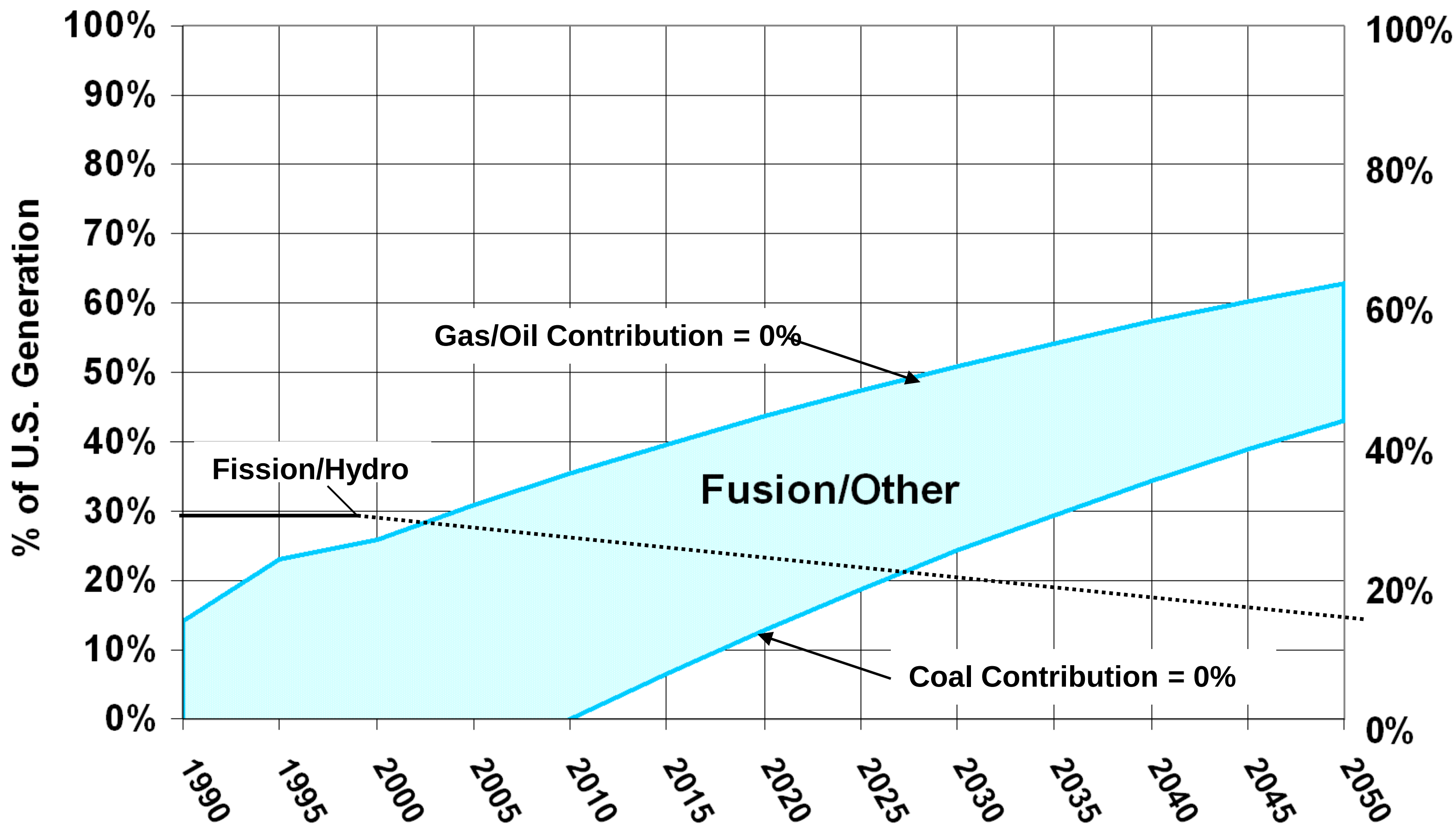
$\frac{\text{"service"}}{GW_e \text{ or } GW_e y}$ X $\frac{\$}{\text{unit "service"}}$ X

Commodity	*Energy Intensity (GJ/1977$)*
New Construc.	32
Elect. Utility	
Auto Repair	23
Railroad	49
Paving	192

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



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.

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.