Life Cycle Energy Cost of Wind and Gas-Turbine Power

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Objectives

- Compare the lifetime energy requirements of wind, coal, natural gas, fission, and fusion power plant technologies.

- Determine a Net Energy Balance for each technology.

- Compare lifetime emissions of CO_2 of each power plant.

Procedures

- A cradle-to-grave approach was used in the analysis of the energy requirements and emissions including material procurement, power plant construction, operation, fuel procurement and power plant decommissioning.

- The input/output and process methodologies of energy accounting were used to determine the energy requirements of power plant processes.

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.

There are Two Methods to Measure Energy Input to Power Plants

Process Chain Analysis (PCA)

unit mass / GW_e or $GW_e y$

X

Material	*GJ/tonne*
Aluminum	207
Concrete	1.4
Copper	131
Stainless Steel	53
Zirconium	1604
Vanadium	3711

GJ / GW_e or $GW_e y$

Input/Output (I/O)

"service" / GW_e or $GW_e y$

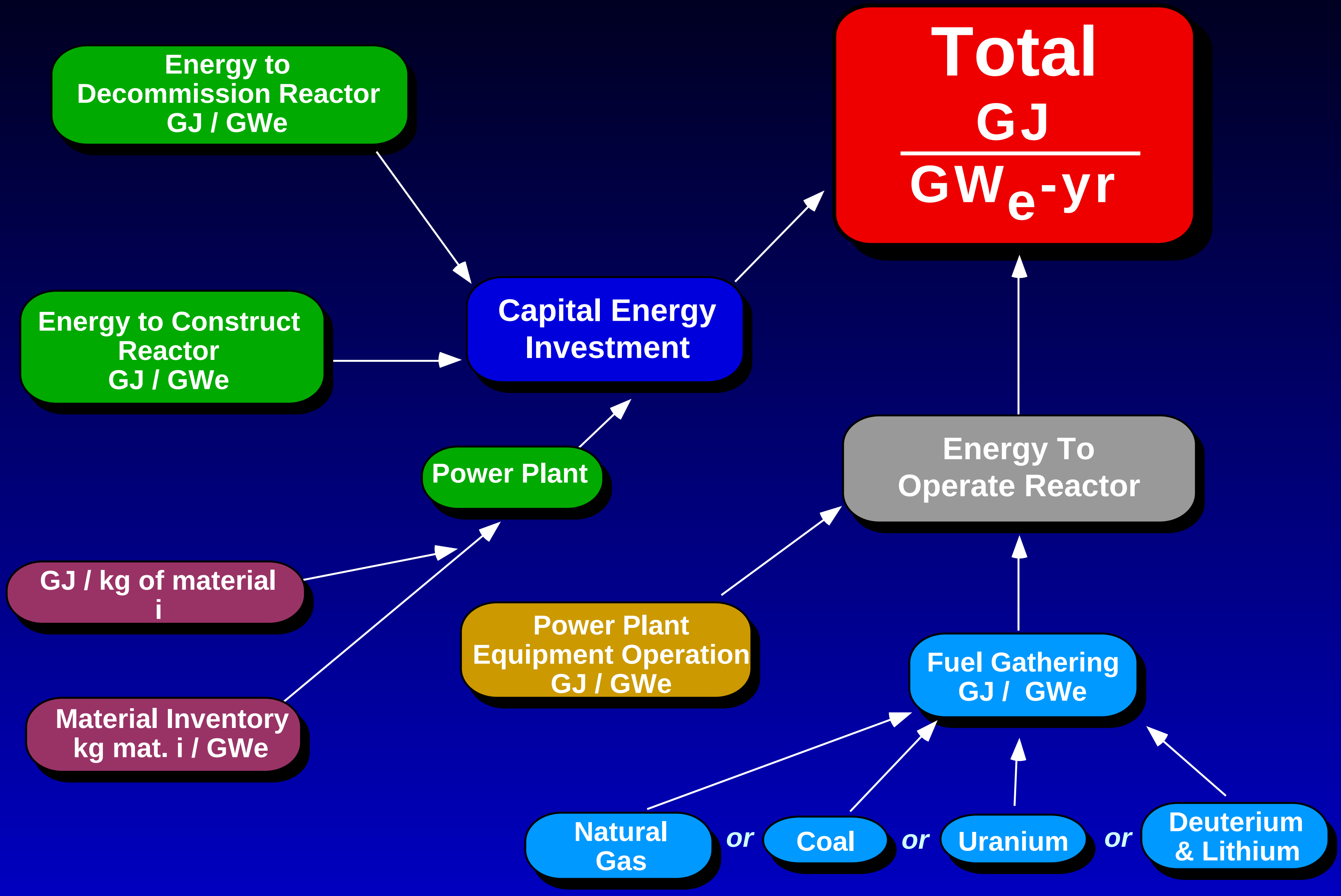
X

$ / unit "service"

X

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

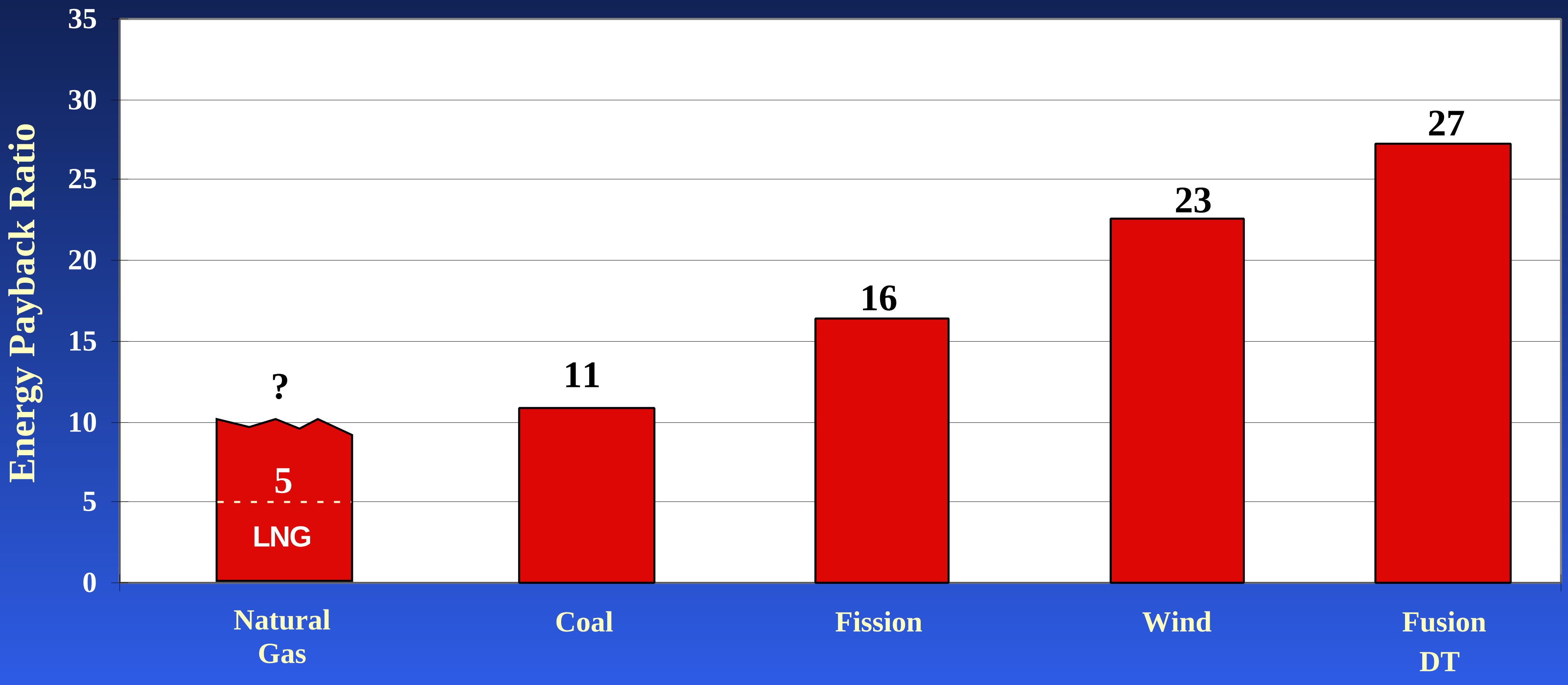
The Energy Investment in a Power Plant is Comprised of Many Components



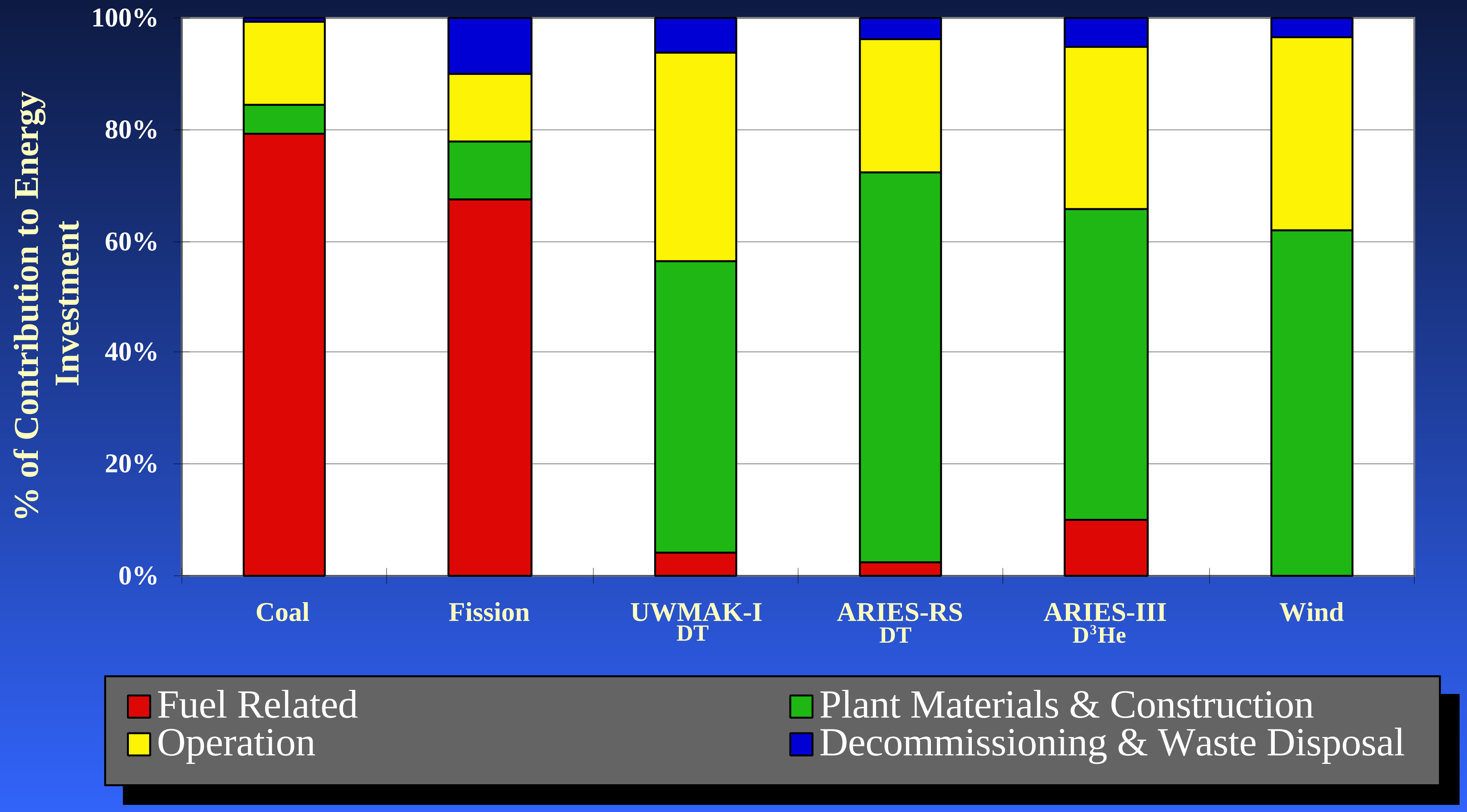
Summary of Power Plant Designs Used to Determine Energy Payback Ratio

Parameter	*Coal*	*Natural Gas*	*Fission*	*Fusion*	*Wind*
Power Level-MW_e	1000	525	1000	1494	25
Fuel	US average/ coal - 1990	Natural Gas	3% enriched U	Deuterium-Tritium	Not appl.
Capacity Factor-%	75	75	75	75	24
Life-CY	40	30	40	40	25
Other Information	• Conventional • Steam	• 3 combustion turbines	• Pressurized Water Reactor • Gas Centrifuge Enrichment	• Tokamak • UWMAK-I	• 3 blade unispeed • No energy storage

The Energy Payback Ratio Varies by a Factor of Nearly 3 Between Coal and Fusion Power Plants



The Contribution to the Energy Payback Ratio is Dominated by Fuel for Coal and FIssion and by Plant Materials/Construction for Fission and Wind Technologies



"Nuclear power produces electricity without emitting any greenhouse gases."
–columnist Ben Wattenberg (Nov. 6, 1997)
The Washington Times

"Nuclear power is a zero-carbon energy source."
–International Nuclear Societies Council (Dec. 1997, p. 72)
Nuclear News

"... a zero-emission source of electricity: nuclear energy."
–Nuclear Energy Institute advertisement (Oct./Nov. 1997, p. 11)
Nuclear Energy Insight

Most People Believe that Nuclear Power and Renewables Do Not Emit Greenhouse Gases

"Wind, photovoltaics, and improved energy efficiency produce no carbon at all."
–Christopher Flavin, October 1989, p. 44
Worldwatch Paper 91

"... a pollution-free power source such as solar energy ..."
–Hilary F. French, January 1990, p. 29
Worldwatch Paper 94

CO_2 Emissions are Calculated from Both Electrical and Thermal Inputs

Electrical

1996 U.S. Electrical Distribution	
Coal	56.5%
Hydro	10.7
Nuclear	21.9
Oil	2.2
Natural Gas	8.7

X

kg CO_2 / MWh	
Coal	974
Hydro	3.1
Nuclear	17
Oil	726
Natural Gas	484

→ **0.605** $\frac{\text{tonnes } CO_2}{\text{MWh}}$

Thermal

(example)

$\frac{\text{Unit of Fuel}}{\text{tonne structural steel}}$

X

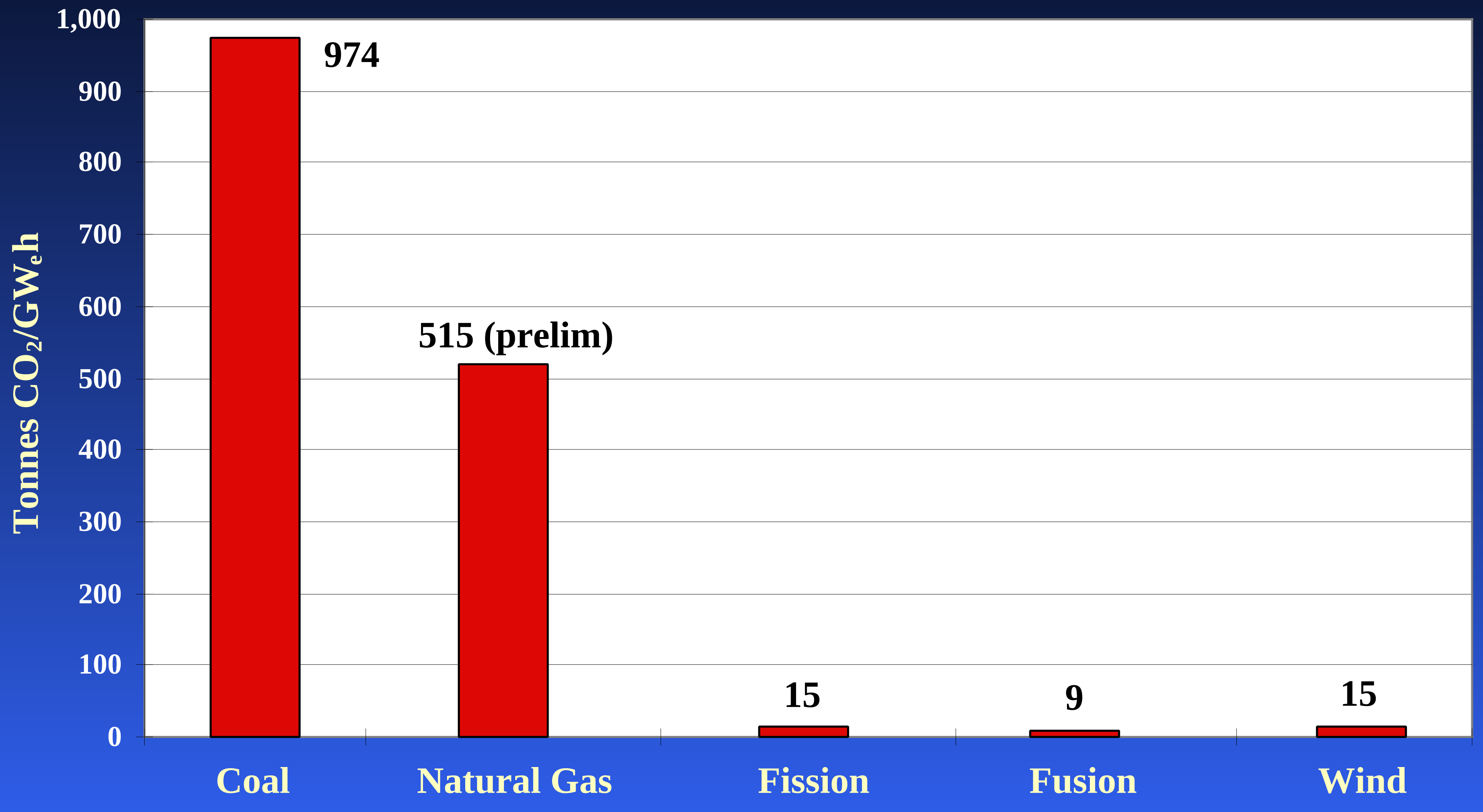
Energy Intensity	
Coal	23 GJ/tonne
Petroleum	0.13 GJ/gal
Natural Gas	0.001 GJ/ft^3
Diesel	0.15 GJ/gal
...	...

X

kg CO_2 / GJ_{th}	
Coal	93
Petroleum	69
Natural Gas	51
Diesel	72
...	...

→ **1.5** $\frac{\text{tonnes } CO_2}{\text{tonnes structural steel}}$

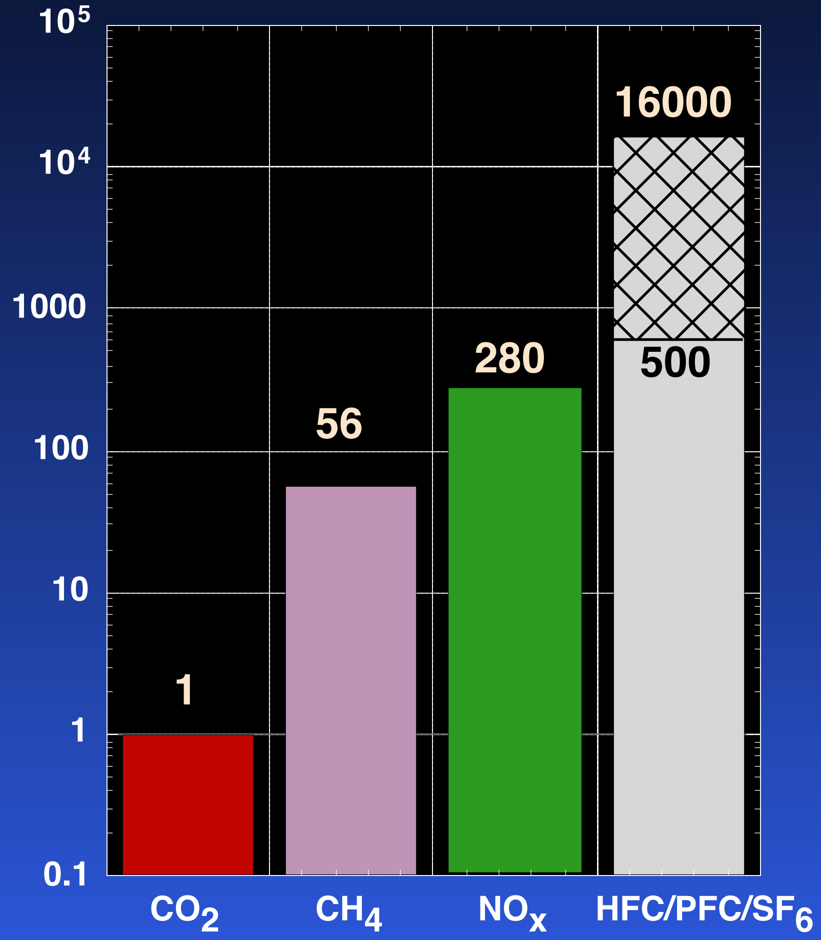
Relative to the CO_2 Emissions of Coal, Those from the Nuclear and Wind Technologies are Low, But Not Zero



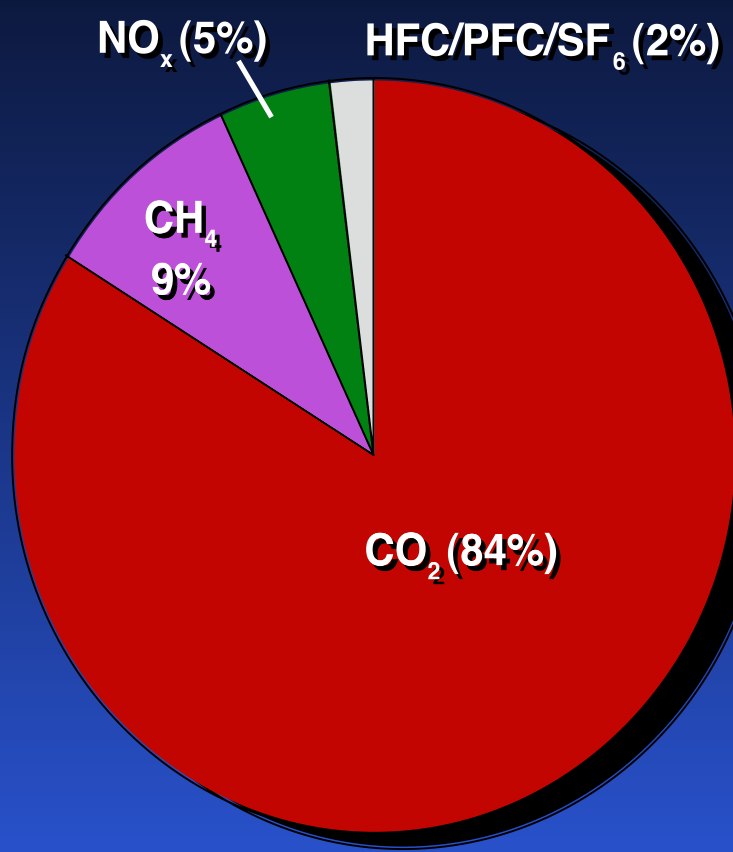
Issues To Be Considered With Respect to Natural Gas Electrical Power Plants

- Exploration and Drilling
- Extraction and Transportation (pipelines)
- Construction of the Power Plant
- Normal Operational and Maintenance
- Reduction of Other Greenhouse Gases (CH_4, NO_x, etc.)
- Decommissioning

The Global Warming Potentials of Greenhouse Gases Vary Over a Wide Range

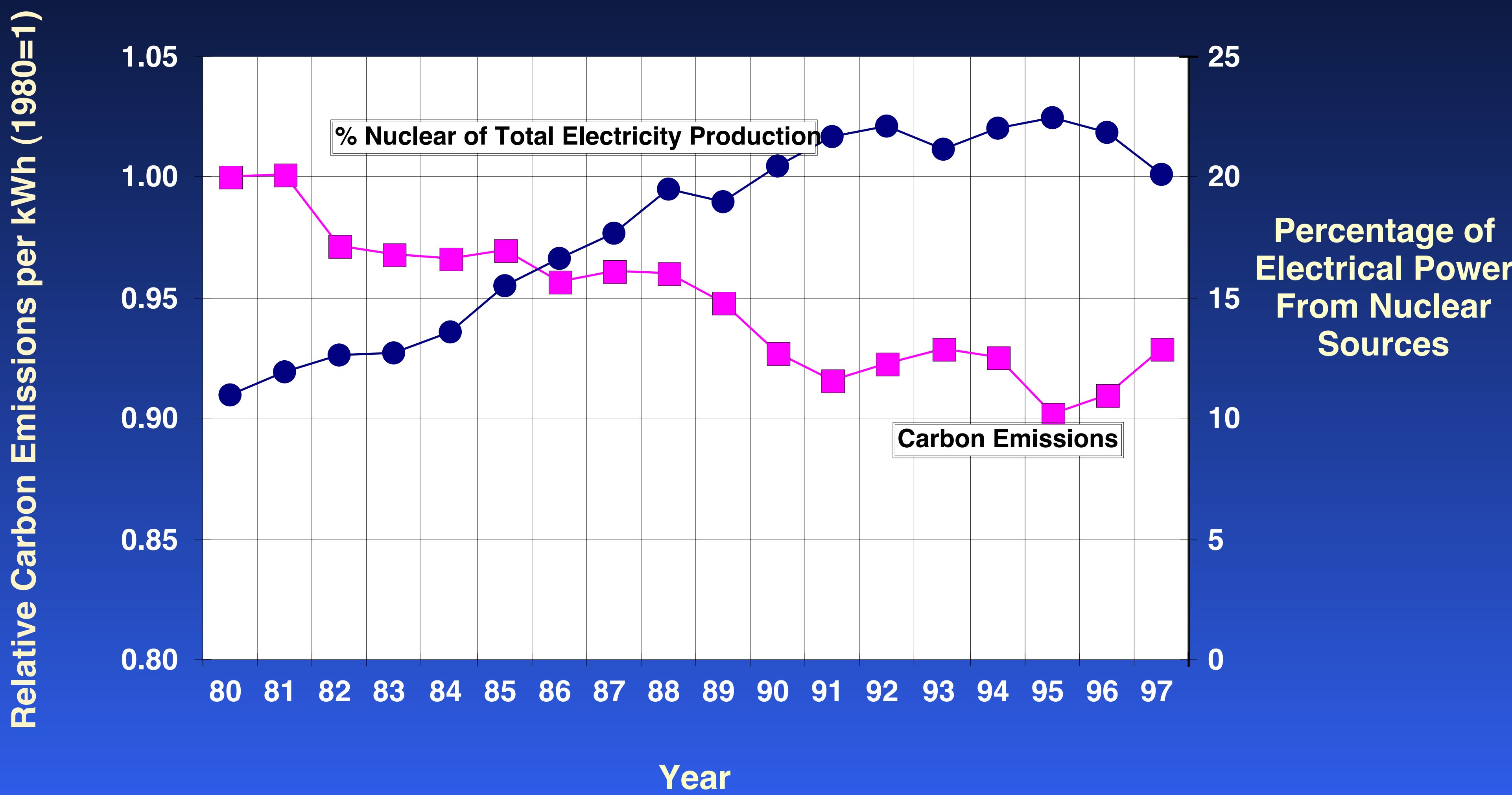


Relative Effect for Equal Masses – 20 years After Release



GWP-Weighted Effect in U.S. 1997

The Introduction of Nuclear Energy Has Lowered the Carbon Emissions from Electrical Power Plants in the U.S.



Preliminary Conclusions

- The procurement of fuel tends to dominate the energy requirements for coal, natural gas, and fission power plants

- The procurement of materials to construct the power plants dominates the EPR of fusion and wind plants

- The CO_2 emissions for fission, fusion, and wind are only 1-2% of coal plants and 2-4% of natural gas facilities

- All electricity producing facilities release CO_2 either directly (coal and natural gas) or indirectly (fission, fusion, & wind)