Energy Payback Ratio and CO_2 Emission Associated with Electricity Generation from a Natural Gas Power Plant – *Preliminary Findings*

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Objective: Net Energy Analysis of electricity generation using a modern natural gas power plant, and development of a Greenhouse Gas Emission Factor for the lifecycle of the system.

Net Energy Analysis:

- A comparison of the useful energy output of a system, with the total input energy consumed by the system in order to produce useful energy.
- Expressed quantitatively as an Energy Payback Ratio (EPR) which can be compared to alternative technologies.

Greenhouse Gas Emission Factor:

- Expressed in terms of tonnes CO_2 emitted per GW-hour electricity produced.
- Can be compared to alternative technologies.

Lifecycle:

- “Birth to Death” of a system including fuel procurement and transportation, plant structural materials and construction, operation, and decommissioning.

REFERENCE NATURAL GAS PLANT

Operating Assumptions:

Gas Turbine (η = 50%)

Plant Capacity = 80%

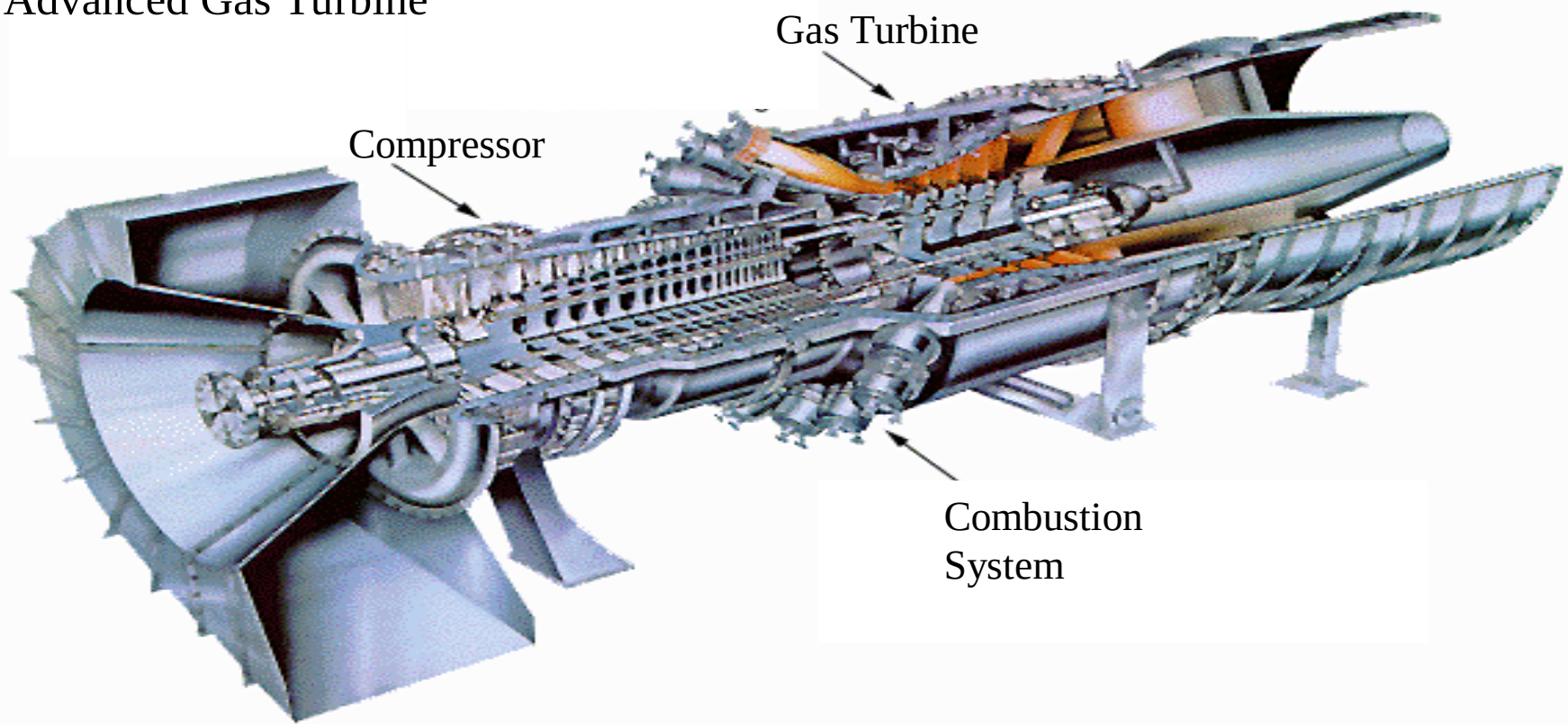
Gross Electrical Power Output: 450 MW_e total from 3 turbines

Annual Electrical Energy Output: 11,352,960 GJ_e (3,153 GW_eh)

Annual Natural Gas Input = 22,705,920 GJ_{th} (6 x 10^8 m^3*)

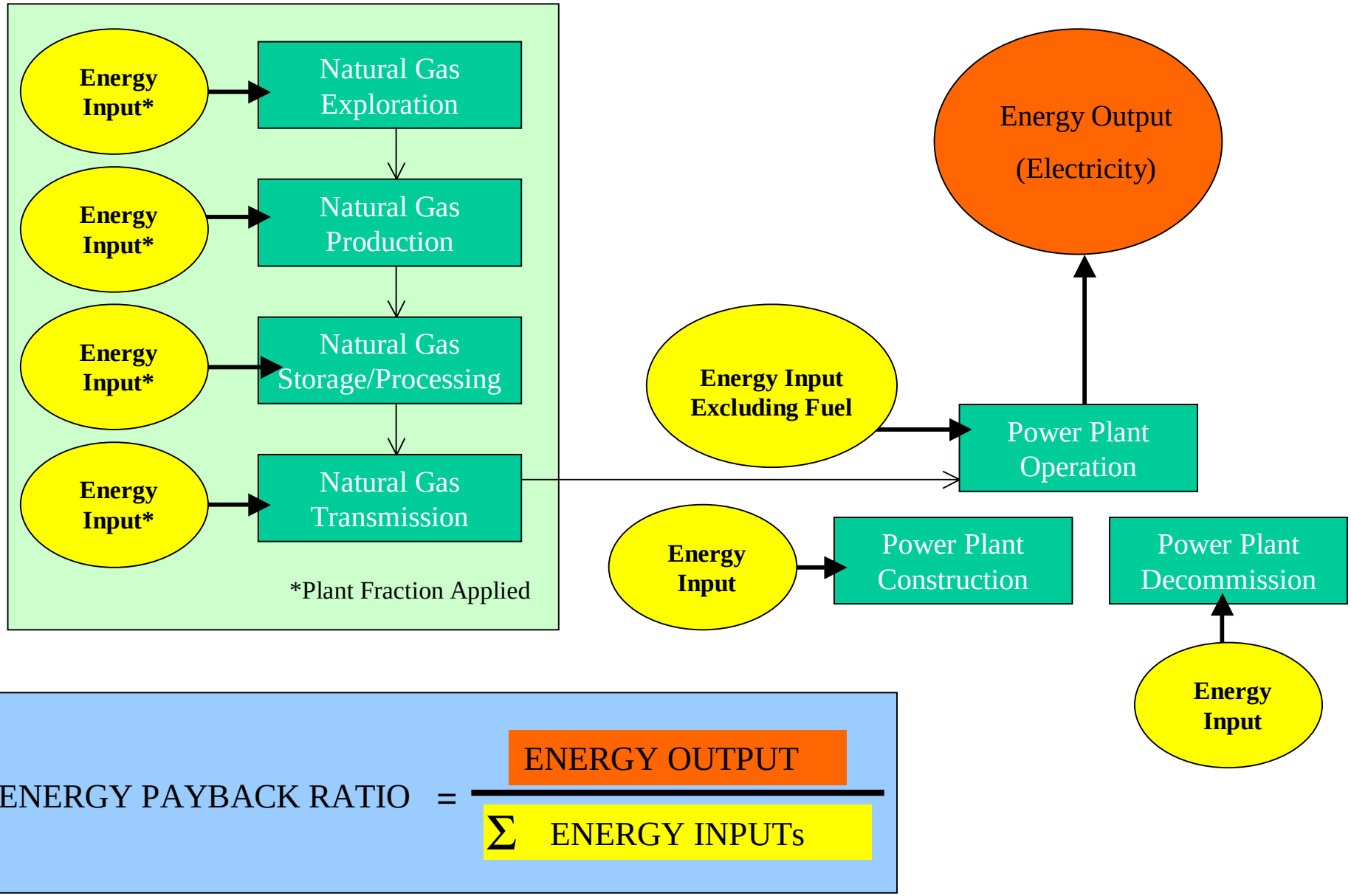
*1020 BTU/ft^3 (38 MJ/m^3)

Advanced Gas Turbine



NET ENERGY ANALYSIS

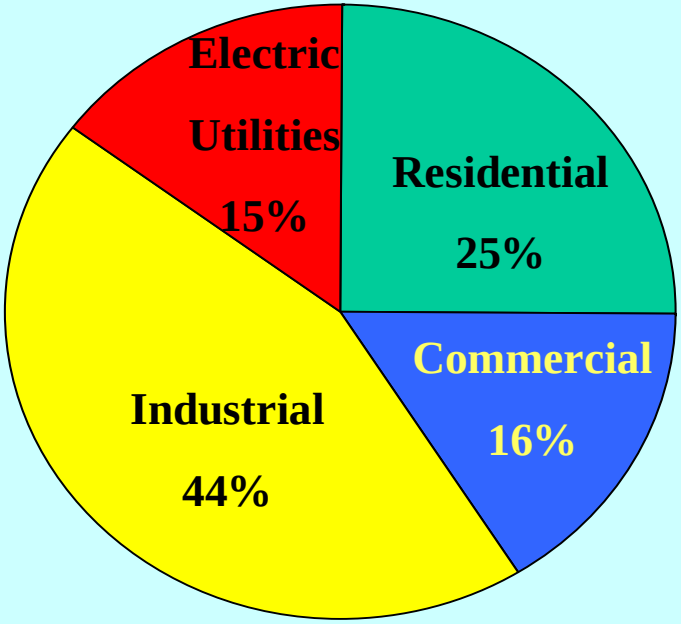
NATURAL GAS TURBINE ELECTRICITY GENERATION



$$\text{ENERGY PAYBACK RATIO} = \frac{\text{ENERGY OUTPUT}}{\sum \text{ENERGY INPUTs}}$$

FUEL RELATED AMORTIZATION PROCEDURE
"Paying for the Pipeline"

U.S. Natural Gas Consumption:



Source: EIA for year 1997

Reference Plant Fraction:

Reference Plant Fuel Consumption:

6.10×10^8 m^3/year

Total US Pipeline Natural Gas Delivered*:

5.35×10^{11} m^3/year

*EIA-0131(97): 1997, Excludes Exports, Imports, & Additions to Storage

Reference Plant Fraction:

$6.10 \times 10^8 / 5.35 \times 10^{11} = 0.114\%$

Example Calculation for Energy Associated with Natural Gas Pipeline:

$$\left|\begin{array}{c}\text{Energy Embodied in U.S. Natural Gas Pipeline}\end{array}\right| \times \left|\frac{1}{30\text{ years}}\right| \times \left|\begin{array}{c}\text{Ref. Plant Fraction (0.114\%)}\end{array}\right| = \text{Energy Embodied per year in Pipeline Allocated to Reference Plant}$$

FUEL RELATED ENERGY INPUTS TO REFERENCE NATURAL GAS PLANT

(includes exploration, production, processing, transmission, etc.)

Materials

•Drilling equipment, wells, processing equipment, pipeline, compressors, measuring and regulating equipment, housing

Labor

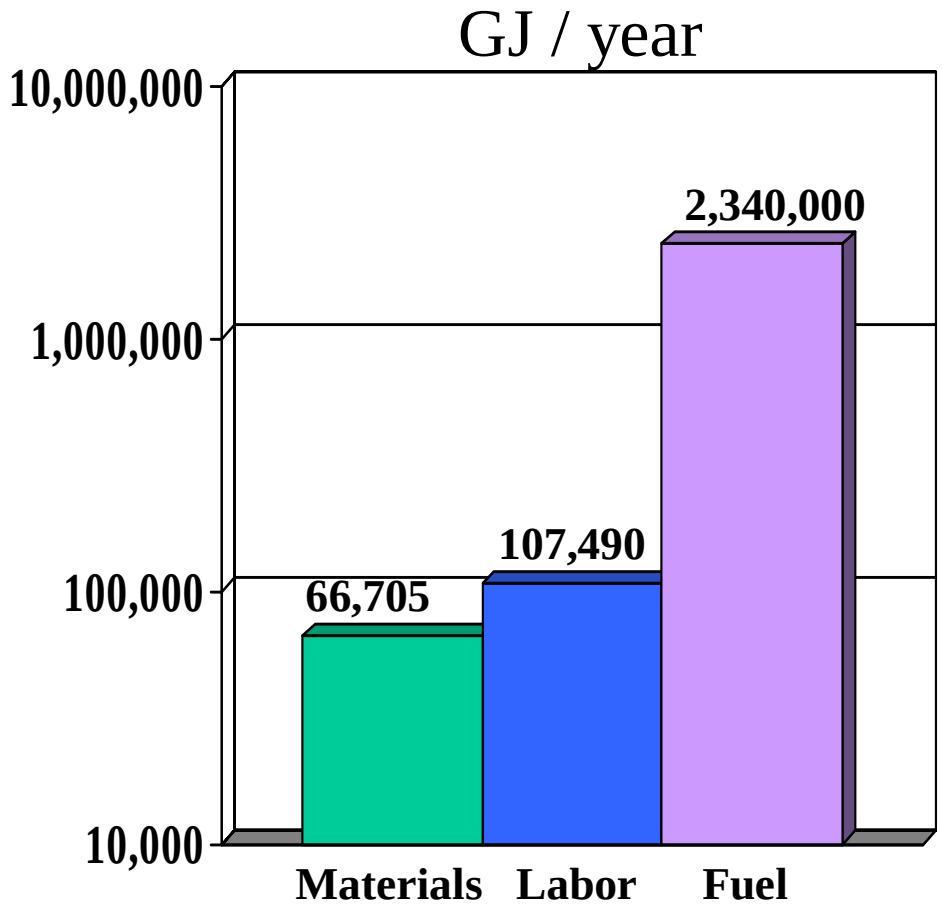
•Installation

•Engineering & Administration

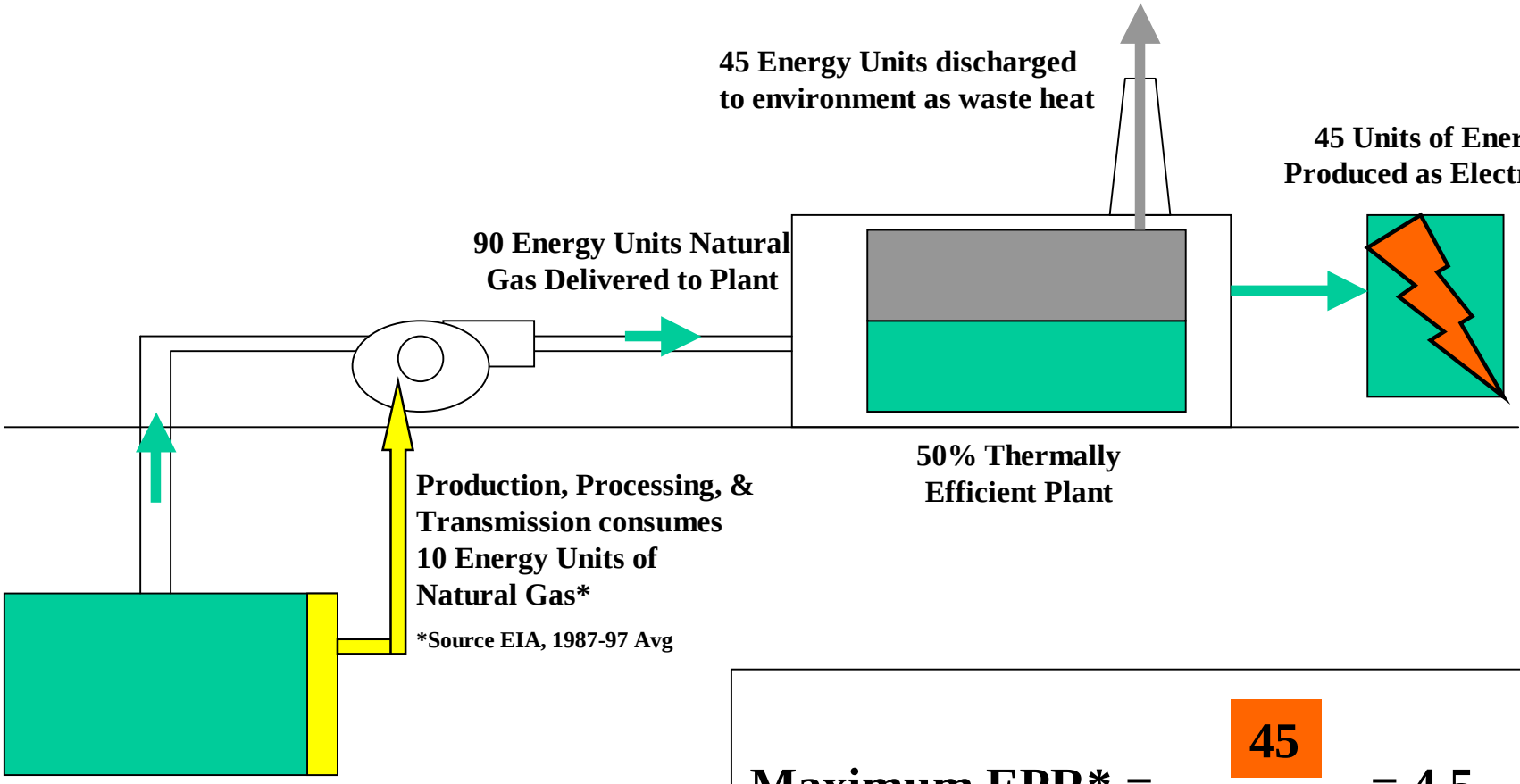
•Operation & Maintenance

Fuel

•Natural gas used for drilling, heating, dehydrators, field & transmission compressors



Maximum Energy Payback Ratio (EPR) for natural gas is limited by the fuel used in production, processing, & transmission



$$\text{Maximum EPR*} = \frac{45}{10} = 4.5$$

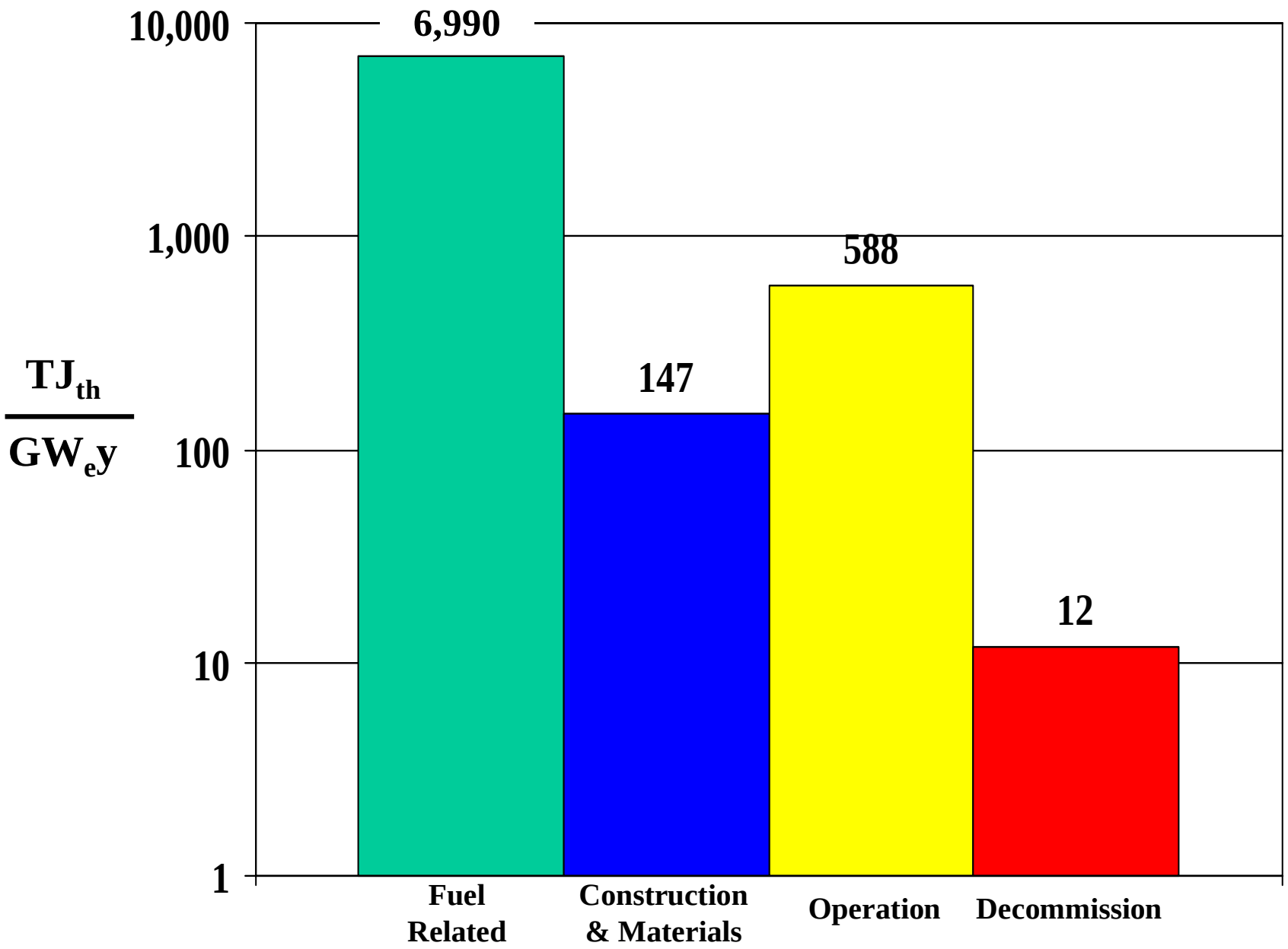
*Accounting for fuel consumed in production, processing and transmission, and plant efficiency only.

ENERGY INPUT DATA TABLE
Input (GJ) per Year of Reference Plant Operation

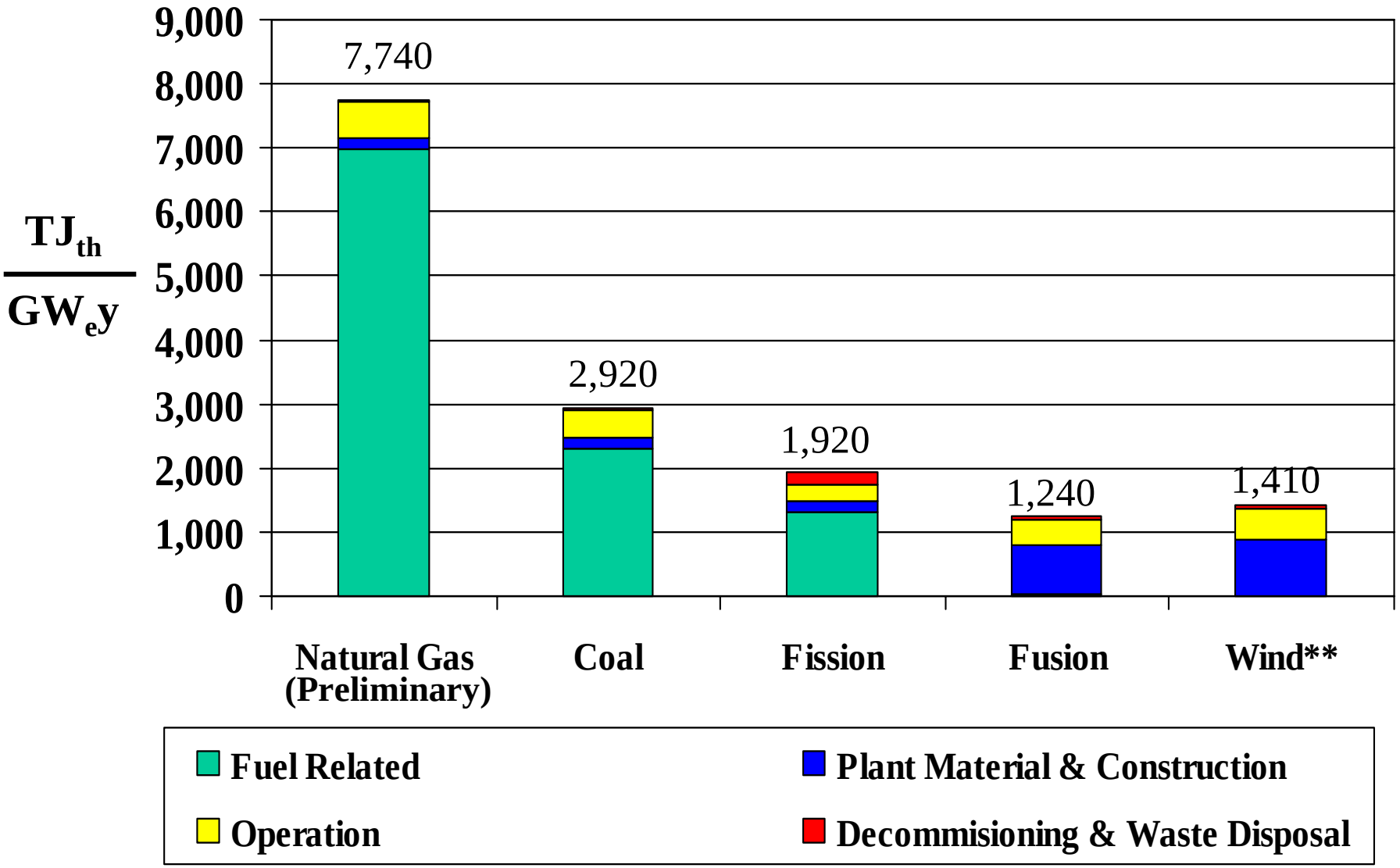
PROCESS	GJ_{th} / Calendar Year
Natural Gas Production Equipment (Installed)	6,889
Natural Gas Production O&M - Fuel	1,424,632
Natural Gas Production O&M - Labor	7,417
Natural Gas Storage and Processing Equipment (Installed)	19,652
Natural Gas Storage and Processing O&M - Fuel	Included with Production
Natural Gas Storage and Processing O&M - Labor	32,205
Natural Gas Transmission Equipment (Installed)	92,574
Natural Gas Transmission Production O&M - Fuel	917,471
Natural Gas Transmission Production O&M - Labor	14,897
Power Plant Materials*	11,205
Power Plant Construction*	18,556
Power Plant Operation	211,750
Power Plant Decommission*	5,047
Land Reclamation	111
TOTAL	**Preliminary 2,798,780**

*Scaled from 1GW Coal Plant

Normalized Net Energy Investment in Natural Gas Electrical Power Plant - Preliminary



Normalized Energy Investment Comparison*



* Previous Work by: S. White, University of Wisconsin

** Wind analysis excludes storage

Preliminary Energy Payback Ratio for Reference Natural Gas Power Plant

Reference Plant Inputs

(GJ_{th} per calendar year of operation)

Fuel Related: 2,516,000

Construction & Materials: 66,100

Operation: 212,000

Decommission: 5,160

Total: 2,800,000

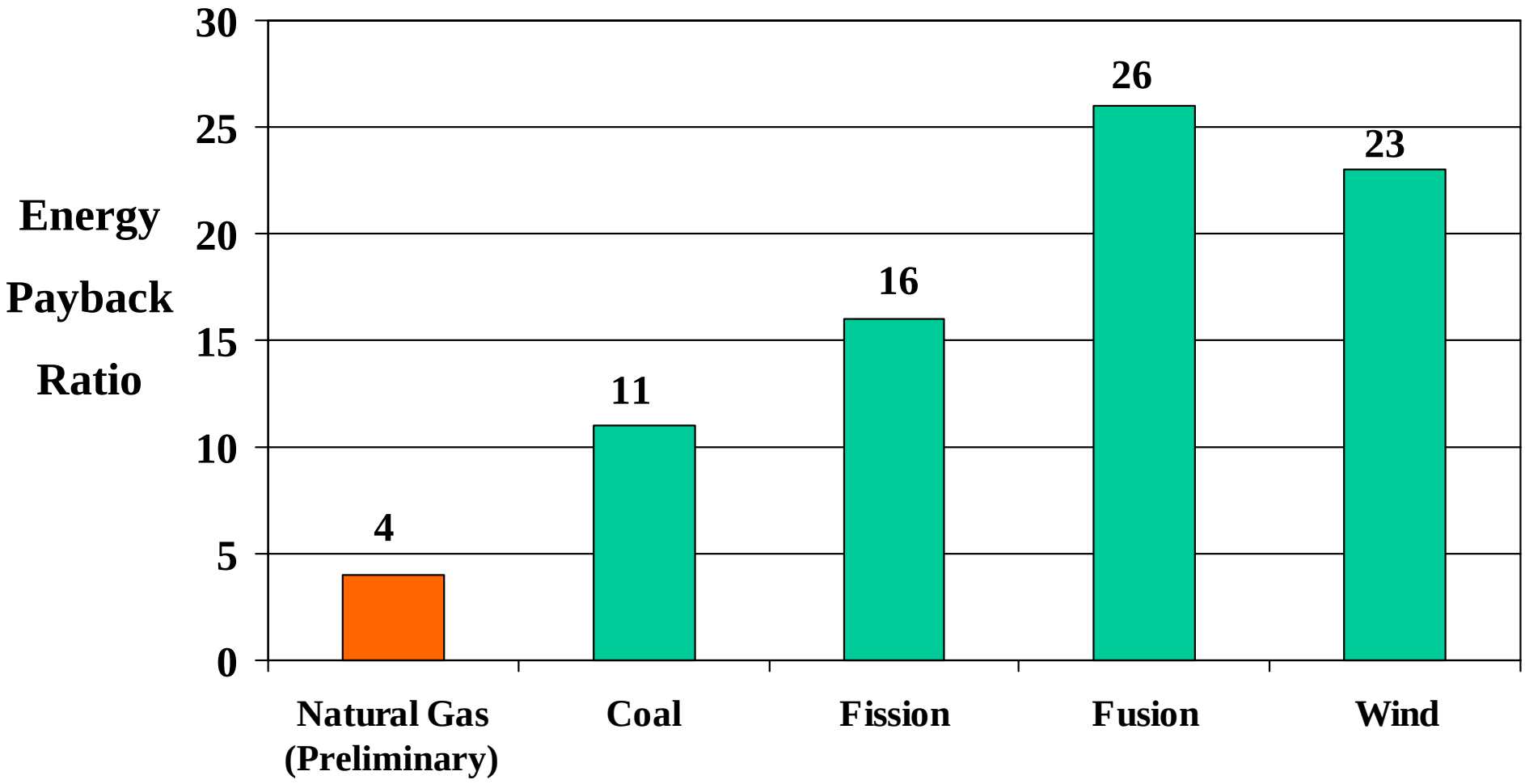
Reference Plant Output

(GJ_e per calendar year of operation)

Net Electrical Output: 11,350,000

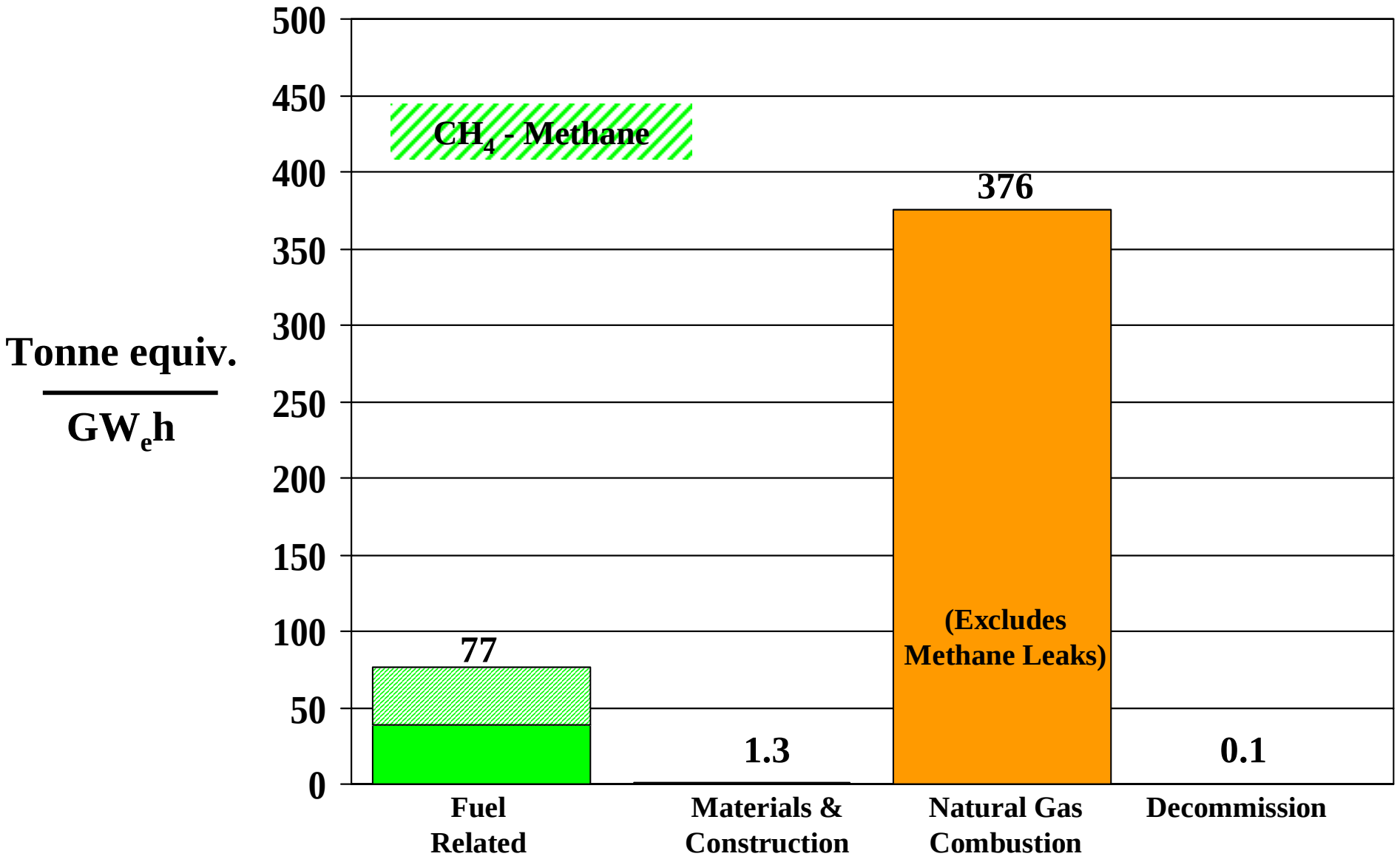
$$\text{ENERGY PAYBACK RATIO} = \frac{11{,}350{,}000\ GJ_e/year}{2{,}800{,}000\ GJ_{th}/year} = 4.06$$

Energy Payback Ratio
Comparison to Previous Work*



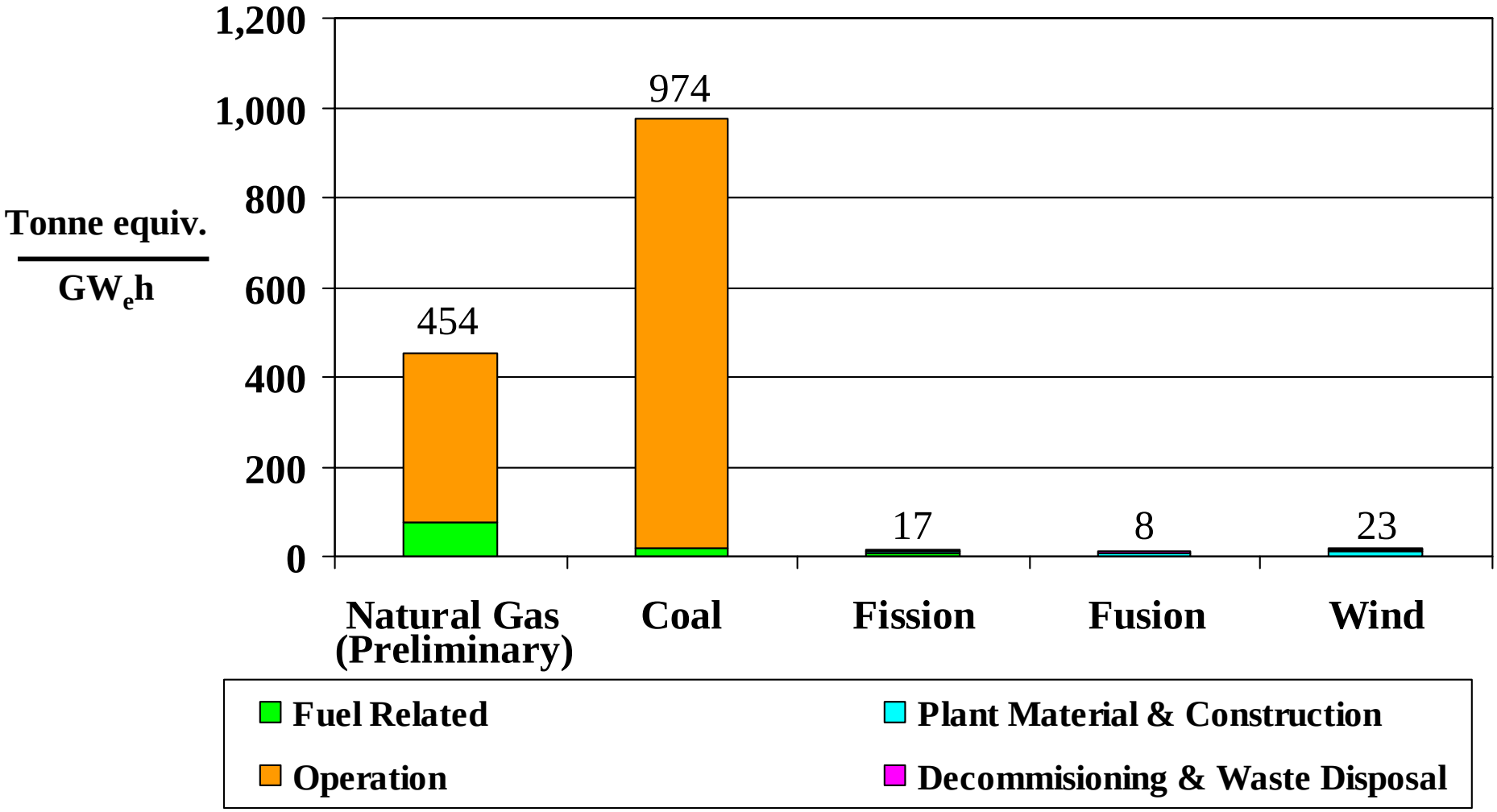
*Previous Work by: S. White, University of Wisconsin

Greenhouse Gas Emissions
Tonne CO_2-equivalent / GW_eh - Preliminary



Greenhouse Gas Emission Comparison

(Tonne CO_2-equivalent / GW_eh)



Coal, Fission, Fusion, Wind data from S. White, University of Wisconsin

Conclusions

- The Energy Payback Ratio for Natural Gas Power Plants is low (4) compared to alternative technologies (11-26).
- The EPR is limited by the use of large quantities of natural gas in the production, processing, and transmission phases of the fuel cycle.
- Our preliminary analysis shows the greenhouse gas emissions (GGE) from natural gas to be 46% of those generated from coal.
- A Recent DOE study* reported GGE from modern gas turbines to be 35-44% of those from conventional coal. Our estimate is slightly above this range, due to the lifecycle analysis of the systems.

*SR/OIAF/98-03