GRI-84/0005.5

THE ECONOMIC BENEFITS OF THE MARINE BIOMASS PROGRAM AT GRI

ANNUAL REPORT
(September 1982-June 1983)

Gas Research Institute
8600 West Bryn Mawr Avenue
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DFI Project Nos. 1267 and 1301

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GRI DISCLAIMER

ACKNOWLEDGEMENTS

The authors acknowledge the support guidance, and insights of our sponsor, Ken Darrow of the Gas Research Institute. Many of the accomplishments described here are a direct result of his effort. We would also like to acknowledge the special contributions of other key GRI personnel including Anne Ashby, Jim Drewry, Joe Rosenberg, Ted Willke, John Sharer and his staff, and Kermit Woodcock and his staff. We also owe thanks to Anita Kirkwood and Cathy Doll who produced this report.

RESEARCH SUMMARY GRI-84/0005.5

Title	The Economic Benefits of the Marine Biomass Program at GRI
Contractor	Decision Focus Incorporated (DFI) GRI Contract Numbers: 5082-511-0596 and 5082-511-0626
Principal Investigators	D. M. Nesbitt and R. A. Marshalla
Report Period	September 1982--June 1983 Final Report
Objective	To provide analytic support and evaluation of GRI's technical-level project area planning and budget-level program planning for the marine biomass project area at GRI.
Technical Perspective	A need existed at GRI to coordinate the technical information at the program and project area level with the planning information collected for setting the budget. Because of the lack of an explicit coordinating link, there was no guarantee of consistency between project plans and the overall GRI program plan. This study provides such a link for the marine biomass project area. The evaluation presented here can serve as an input to GRI's Project Appraisal Methodology (PAM) evaluation process used for program planning at GRI as well as providing strategic guidance for marine biomass project area management at GRI.
Results	The overall economic benefits that will occur if marine biomass is successful are substantial; however the probability of achieving those benefits is assumed by GRI to be relatively small. To illustrate, using a five percent real discount rate, the present value of overall economic benefits if marine biomass succeeds rather than fails under current GRI funding is 42.69 billion dollars. This is equivalent to an annualized benefit over the next 45 years of 2.40 billion dollars per year. The benefits specifically attributable to GRI, using a five percent real discount rate and GRI's current activities in marine biomass, is 7.88 billion dollars, which is equivalent to an annualized benefit of 440 million dollars per year in each of the next 45 years. This would yield roughly a $0.022/MMBtu reduction in the price of all gas in every one of the next 45 years. Therefore, GRI's R&D activities can achieve roughly 18 percent of the maximum possible expected benefits. The analysis suggests that marine biomass is best viewed as a "long-shot" technology. The project area provides a small probability of a bonanza and a large probability of

no payoff at all. Nonetheless, the small probability multiplied by the large economic benefit under the bonanza outcome yields an expected benefit that is large enough to justify activity in the marine biomass area. The risk of pursuing this technology must be balanced against that of competing R&D activities at GRI.

Technical Approach

The calculations presented here were made using the DFI energy model, which has been extensively revised to meet the needs of this evaluation. This analysis represents marine biomass at a relatively aggregate level; that is, the various potential sources of feedstock are not considered in detail. Technology cost and performance estimates used in this analysis were provided by GRI personnel.

The degree and timing of penetration of marine biomass into the energy market and the benefits achieved depend on the technical outcomes of marine biomass technologies as well as those of competing gas technologies. The most important uncertainties affecting marine biomass benefits appear to be (a) coal gasification technical outcomes, (b) marine biomass technical outcomes, and (c) unconventional gas technical outcomes. This analysis computes the benefits of current versus zero funding of GRI's marine biomass project area and takes explicit account of the first two uncertainties. The series of decisions and potential future outcomes that can occur in the marine biomass project area are enumerated and structured in decision tree format. Each path in the decision tree describes a possible scenario of technical success or failure for marine biomass technology.

Project Implications

This analysis was based upon preliminary cost estimates for the marine biomass technology in advance of detailed cost engineering studies that have since been completed. The preliminary baseline estimate, designated in the report as GE-RMP, is quite close to the advanced case estimated developed by Ralph M. Parsons Co. (GRI project 5082-511-0627), but significantly lower than the Parsons base case. This change does not alter the qualitative conclusions of the DFI analysis; however, it indicates that marine biomass may be an even longer range, riskier technology than was indicated by the DFI analysis and may have somewhat lower expected benefits than those indicated here. Subsequent supply project area analyses using the DFI model will incorporate the newer cost estimates for this and other supply technologies.

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Introduction and Summary

This report describes an economic evaluation of the benefits of the marine biomass research and development (R&D) project area at the Gas Research Institute (GRI). The calculations described here have been made using the Decision Focus Incorporated (DFI) energy model, which has been extensively revised to meet the needs of this evaluation. The economic benefits presented here are calculated in the same format as the inputs to the GRI Program Appraisal Methodology (PAM). Thus the evaluation serves as a guide for this year's PAM evaluation process for the marine biomass program area.

This analysis considers marine biomass at a relatively aggregate level. For example, we do not distinguish the various potential sources of feedstock in detail (e.g., Pacific kelp versus sargassum). Rather, we view marine biomass as an aggregate commodity and analyze how gas from that commodity will compete with alternative sources.

We have assessed not only the economic benefits of technical success relative to failure of the marine biomass program area but also the portion of those benefits that can be specifically attributed to GRI funding. As with our evaluations of other GRI technologies, three types of economic benefit measures have been calculated:

1. the direct benefit to consumers, which takes account of both the reduction in gas price and the increased consumption of gas at this lower price,
2. overall economic benefit, which takes account of direct consumer benefits as well as indirect benefits that arise from changes in lease bonus payments, royalties, income and other taxes, and corporate profits.

3. the increase in marine biomass production resulting from successful R&D.

For this analysis, we have used technology cost and performance extimates provided by GRI's marine biomass personnel (Kimon Bird), land biomass personnel (Pete Benson), unconventional gas personnel (John Sharer), and coal gasification personnel (Vern Hill).

The overall economic benefits that will occur if marine biomass is successful are substantial. However, the probability of achieving these benefits is by GRI's estimate relatively small. To illustrate, using a five percent real discount rate, the present value of overall economic benefits if marine biomass succeeds rather than fails under current GRI funding is $42.69 billion. This is equivalent to an annualized benefit over the next forty-five years of $2.40 billion per year. This $42.69 billion present value figure does not represent the benefit specifically attributable to GRI's activities in marine biomass; rather, it represents the magnitude of economic benefits that are possible if marine biomass technologies can be made to succeed. That is, it represents the maximum "prize" marine biomass R&D is seeking.

The benefits specifically attributable to GRI comprise only a fraction of this total. Using a five percent discount rate, the expected value of GRI's current R&D activities in marine biomass is $7.88 billion. This is equivalent to an annualized benefit stream of $440 million per year in each of the next forty-five years. This is equivalent to roughly a $0.022 per MMBtu reduction in the price of all gas in every one of the next forty-five years. To summarize, GRI's R&D activities can achieve roughly 18.5 percent of the maximum "prize" possible if marine gas succeeds. The magnitude of economic benefits from GRI's marine biomass R&D program appear to be large relative to GRI's annual R&D expenditures in this project area even though as we shall see the probability of technical success is not large.

This analysis suggests that marine biomass is best viewed as a "long-shot" technology. The program provides a small probability of a bonanza and a large probability of no payoff at all. Nonetheless the small probability multiplied by the large economic benefit under the bonanza outcome yields an expected benefit that is large enough to justify activity in the marine biomass area. Of course, a technology with a small probability of a large payoff is risky, and this risk must be balanced against that of competing R&D activities at GRI.

Problem Formulation

The degree and timing of penetration of marine biomass into the energy market and the benefits achieved depend on the technical outcomes of marine biomass technologies as well as those of competing gas technologies. Based on our previous studies for GRI, the most important uncertainties affecting marine biomass benefits appear to be:

- coal gasification technical outcomes
- marine biomass technical outcomes
- unconventional gas technical outcomes.

This analysis computes the benefits of current versus zero funding of GRI's marine biomass program area and takes explicit account of the first two uncertainties. Based on the results of last year's analysis,* the impact of a source such as coal gasification, which competes direcly with marine biomass in the same time frame, is more important than the impact of a source such as unconventional gas, whose primary market impact occurs before marine biomass becomes commercial. In addition, rather than explicitly considering uncertainty in gas demand, we have instead in an approximate manner calibrated gas demand to the level of demand in the GRI baseline projection and assumed a price elasticity to characterize variation about that calibrated value. We have chosen this calibration approach to facilitate analytical consistency among the

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*See [1].

various divisions of GRI. It is straightforward (but more expensive) to explicitly represent uncertainty in gas demand.

To structure our analysis, we enumerate the series of decisions and potential future outcomes that can occur in the marine gas project area. See Figure 1. The leftmost node in the figure (a square node) represents the two GRI funding alternatives considered for the marine biomass program area--current funding (which represents a commitment for GRI to fund the technology at roughly current levels until commercialization or definitive technical failure) and zero funding (which represents abandonment of marine biomass R&D by GRI).

Moving to the second node from the left (a circular node), we have represented the different degrees of technical success or failure marine biomass might achieve. For purposes of this analysis, we have defined two degrees of technical success and one degree of technical failure.

Marine biomass R&D has now proceeded to the point where the General Electric (GE) design for Pacific kelp gasification is probably technically feasible (although perhaps not economically justified). We define technical failure to mean than no new marine biomass gasification technology ever "beats" the current GE small 3 MMcf/day plant design. Furthermore, technical failure is assumed to mean that substrate costs will never be reduced from currently anticipated levels, alginate byproducts will never be sold and therefore the technology will never receive byproduct credits, and currently estimated plant contingency costs will never be reduced. In defining technical failure, we have used the GE small plant estimate in [2].

The tree in Figure 1 indicates that technical failure can occur if GRI funds marine biomass at current levels as well as if GRI terminates its marine biomass program. The tree indicates that the probability of technical failure under current funding is assumed to be 0.5, as specified by marine biomass project personnel at GRI. The tree also indicates the

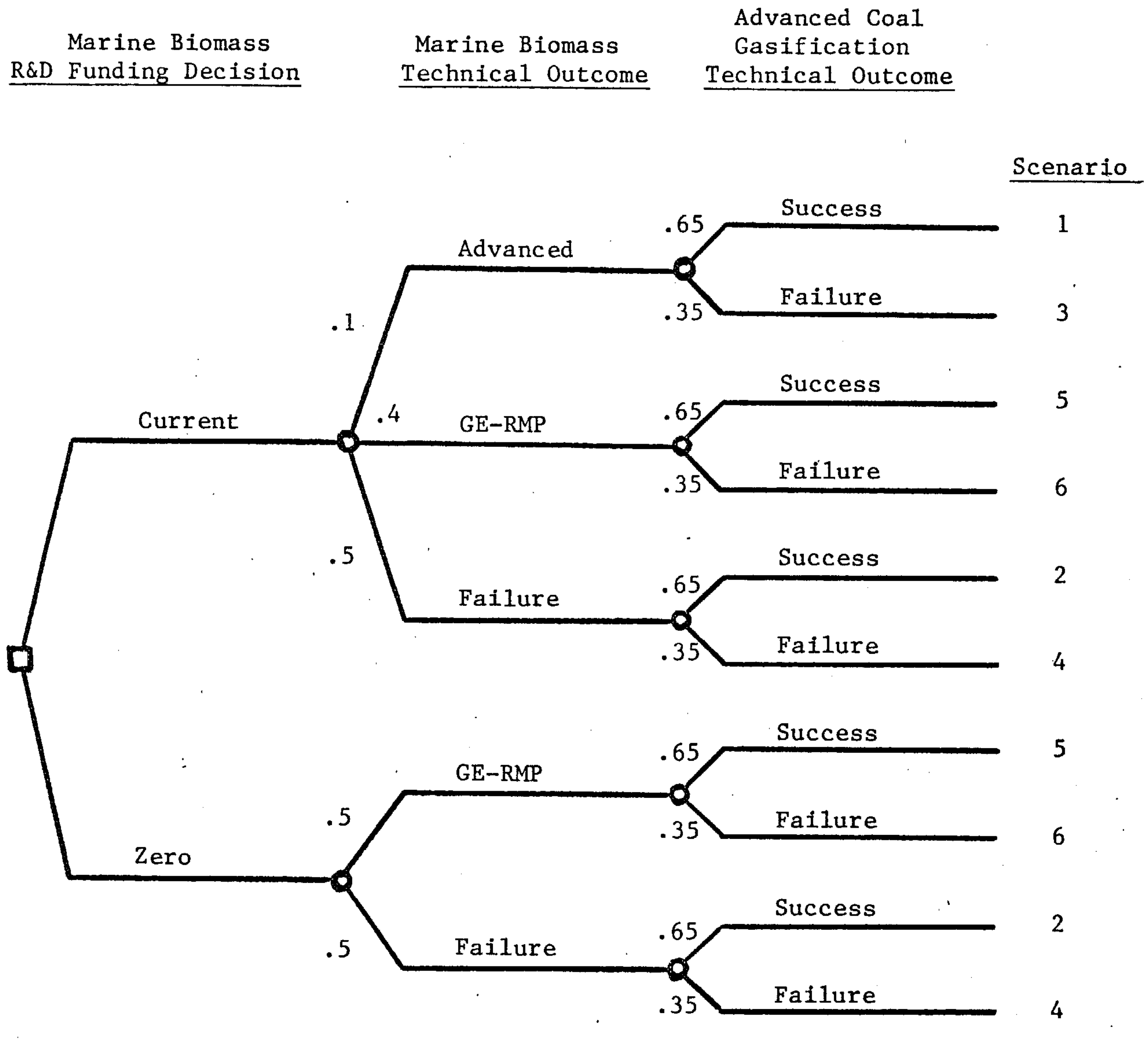

Figure 1. Marine Biomass--Decision Tree

probability of technical failure under zero funding to be 0.5. That is, the probability that marine biomass R&D ultimately fails is assumed to be independent of GRI's funding decision in this area. As we shall soon see, however, the degree of technical success is assumed to depend heavily on GRI's marine biomass funding decision. The benefits of GRI's marine biomass program arise from the relatively higher degree of technical success that can be achieved by GRI's R&D activities.

If GRI terminates funding in the marine biomass area, it is assumed that some other organization such as GE would continue to fund R&D, albeit at a reduced scope and rate. In this case it is assumed that the best R&D outcome possible would be to obtain the same small-scale 3 MMcf/day GE plant but with much reduced substrate costs and with marketable alginate byproducts. This plant would be commercially available in the year 2000. Scaleup to larger plants would not be accomplished, however, nor would currently estimated plant contingencies be eliminated. We have termed this technical outcome the "GE-RMP" case, the designation used in [2]. The tree indicates that the GE-RMP outcome, a modestly successful technical outcome, can occur whether GRI funds marine biomass R&D or not. If GRI discontinues marine biomass funding we assume there would be a 0.5 probability of obtaining the GE-RMP outcome and a 0.5 probability of technical failure. If GRI continues to fund marine biomass at current levels, there would still be a 0.5 probability of technical failure, but now a probability of 0.5 of achieving an outcome better than or equal to the GE-RMP outcome. Specifically, we assume that this 0.5 probability of success is comprised of a 0.4 probability of achieving the GE-RMP outcome along with a 0.1 probability of achieving an even better outcome (to be described shortly). Expressed alternatively, if GRI funds marine biomass at current levels, it is possible to achieve a technical breakthrough relative to the GE-RMP technology. On the other hand, if GRI discontinues marine biomass, it is impossible to ever beat the GE-RMP technical outcome.

In summary, we assume that if GRI continues funding at current levels, it will potentially have a major impact on the direction of the marine biomass technology. In particular, it is assumed that GRI's presence opens the possibility of a breakthrough in marine biomass gasification technology. If R&D is successful given current funding, we assume that an additional plant design becomes available in which substrate costs are substantially reduced, markets for byproducts are developed and byproduct credits offset some of the variable operating cost, and plant scaleup to 1.8 MMcf/day is achieved at an attractive scale factor (0.7). In particular, we have assumed that the breakthrough case is represented by the "advanced technology" case in [2]. It is fair to state that this breakthrough outcome, which it is assumed can only occur under current GRI funding, represents a "bonanza" outcome.

The tree in Figure 1 indicates that current GRI funding can produce the breakthrough outcome with probability 0.1 and the GE-RMP outcome with probability 0.4. This is equivalent to the statement that the probability of success given current funding is 0.5, and the conditional probability that the breakthrough occurs given that marine biomass succeeds is 0.2. In other words, if GRI knew in advance that its marine biomass R&D program would be successful, it would assign a 20 percent chance that the breakthrough outcome would occur and an 80 percent chance that the GE-RMP outcome would occur.

To summarize, Table 1 gives the marine biomass technology cost and performance parameters under failure. Table 2 gives the cost and performance parameters under the GE-RMP outcome, and Table 3 gives the parameters if marine biomass achieves the breakthrough outcome.

The third level of the tree in Figure 1 depicts the uncertain technical outcome of the coal gasification project area. In previous GRI studies, we have found that advanced coal gasification is the primary competitor against marine biomass. It is known that both are based on abundant resources, and both are directed at the mid- to long-term. Although the timing of coal gasification can have an important effect on

Table 1

MARINE BIOMASS GASIFICATION
(Failure)

Never available during study horizon

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Table 2

MARINE BIOMASS GASIFICATION
GE-RMP

GE-RMP Process (includes PDA's & by-product credits)

Initial Year of Commercial Availability	2000
Nameplate Capacity of Representative Plant	1.095×10^{6} MMBtu/Yr (3 MMCFD)
Capital Cost of Representative Plant (excluding AFUDC & including PDA's)	See footnote.
Initial Plant	$\$54.7 \times 1.56 \times 10^{6}$ $= \$85.56 \times 10^{6}$
Mature Industry	$85.56/1.1 \times 10^{6} = \$77.78 \times 10^{6}$
Plant Stream Factor	0.95
Annual O&M Costs (including fuel with by-product credits subtracted)	$(\$5.3 - 5.0) \times 10^{6}$ /Yr $= \$0.3 \times 10^{6}$ /Yr
Plant Life	20 Years
Fraction of Capital Financed by Equity	0.50

Model Inputs

$$SCC = \frac{\text{capital cost}}{\text{nameplate capacity}} = \frac{\$85.56 \times 10^{6}}{1.095 \times 10^{6}\ \text{MMBtu/Yr}} = \$78.14/\text{MMBtu/Yr}$$

$$O\&M = \frac{\text{annual O\&M costs}}{(\text{stream factor})\text{x}(\text{nameplate capacity})} = \frac{\$.3 \times 10^{6}\ /\text{Yr}}{0.95 \times 1.095 \times 10^{6}\ \text{MMBtu/Yr}}$$

$$= \$0.29/\text{MMBtu}$$

Note: All costs expressed in constant 1982 dollars. Feedstock: giant kelp, Pacific Coast. Capital cost has been adjusted by a contingency factor of 1.56 which results from using a 100% contingency on substrate, 50% on planting cost, and 15% on all other capital cost components. Mature industry capital costs are assumed to be 10% lower than first plant costs.

Source: GRI.

10/13/82

Table 3

MARINE BIOMASS GASIFICATION
ADVANCED TECHNOLOGY

Advanced Process (including PDA's and by-product credit)

Initial Year of Commercial Availability	2000
Nameplate Capacity of Representative Plant	6.570×10^{6} MMBtu/Yr (18 MMCFD)
Capital Cost of Representative Plant (excluding AFUDC & including PDA's)	See footnote.
Initial Plant	$\$122.6 \times 1.48 \times 10^{6}$ $= \$178.59 \times 10^{6}$
Mature Industry	Same as initial plant.
Plant Stream Factor	0.95
Annual O&M Costs (including fuel with by-product credit subtracted)	$(\$31.8 - 10.0) \times 10^{6}$ /Yr $= \$21.8 \times 10^{6}$ /Yr
Plant Life	20 Years
Fraction of Capital Financed by Equity	0.50

Model Inputs

$$\text{SCC} = \frac{\text{capital cost}}{\text{nameplate capacity}} = \frac{\$178.59 \times 10^{6}}{6.57 \times 10^{6}\ \text{MMBtu/Yr}} = \$27.18/\text{MMBtu/Yr}$$

$$\text{O\&M} = \frac{\text{annual O\&M costs}}{(\text{stream factor})\times(\text{nameplate capacity})} = \frac{\$21.8 \times 10^{6}\ /\text{Yr}}{0.95 \times 6.57 \times 10^{6}\ \text{MMBtu/Yr}}$$

$$= \$3.49/\text{MMBtu}$$

Note: Uses 0.7 power kW scaling. All costs expressed in constant 1982 dollars. Feedstock: giant kelp, Pacific Coast. Capital cost has been adjusted by a contingency factor of 1.48 which results from using a 100% contingency on substrate, 50% on planting cost, and 15% on all other capital cost components.

Source: GRI.

the benefits of marine biomass, the cost at which gas can ultimately be produced from coal is the most important uncertainty with regard to marine biomass. The coal gasification project area is characterized by one of two possible outcomes:

- Technical success, which is represented by the coal gasification technology characterization sheets in Tables A.1 and A.2 in the Appendix. The probability of achieving technical success given current funding is assumed to be 0.65 as indicated in the tree.
- Failure, which implies that no advanced coal gasification technology will beat Lurgi. The Lurgi technology is characterized in Tables A.3 and A.4 in the Appendix.

We do not intend to imply that the uncertainties explicitly considered in the tree are the only uncertainties that could affect the marine biomass program area. Indeed, under certain assumptions, the availability of conventional natural gas, low cost land biomass gas, inexpensive Mexican or Canadian gas, low cost LNG, or some other variable might have a significant impact on the benefits of marine biomass R&D. It is straightforward to include these uncertainties in the tree in Figure 1, but at the expense of more "bushiness" in the tree and therefore more complexity in the analysis.

The marine biomass funding alternatives, the marine gas technical outcomes, and the coal gasification technical outcomes defined previously define ten possible future combinations of events corresponding to the ten terminal branches of the tree in Figure 1. However, careful inspection of the combinations of events leading to these terminal branches shows that there are only six distinct combinations of events (i.e., six distinct scenarios). These six scenarios defined by the tree are numbered near the corresponding terminal branches. Henceforth, we will refer to these scenarios by number. We should emphasize that all GRI technologies not enumerated in Figure 1 are assumed to succeed given current funding, and all non-GRI technologies are assumed to achieve their expected technical outcomes. The assumption that all other GRI technologies not specifically indicated in Figure 1 will succeed given current funding slightly understates the magnitude of benefits of marine biomass R&D. Thus this analysis will be slightly conservative with regard to the magnitude of economic benefits of marine biomass R&D.

The Model

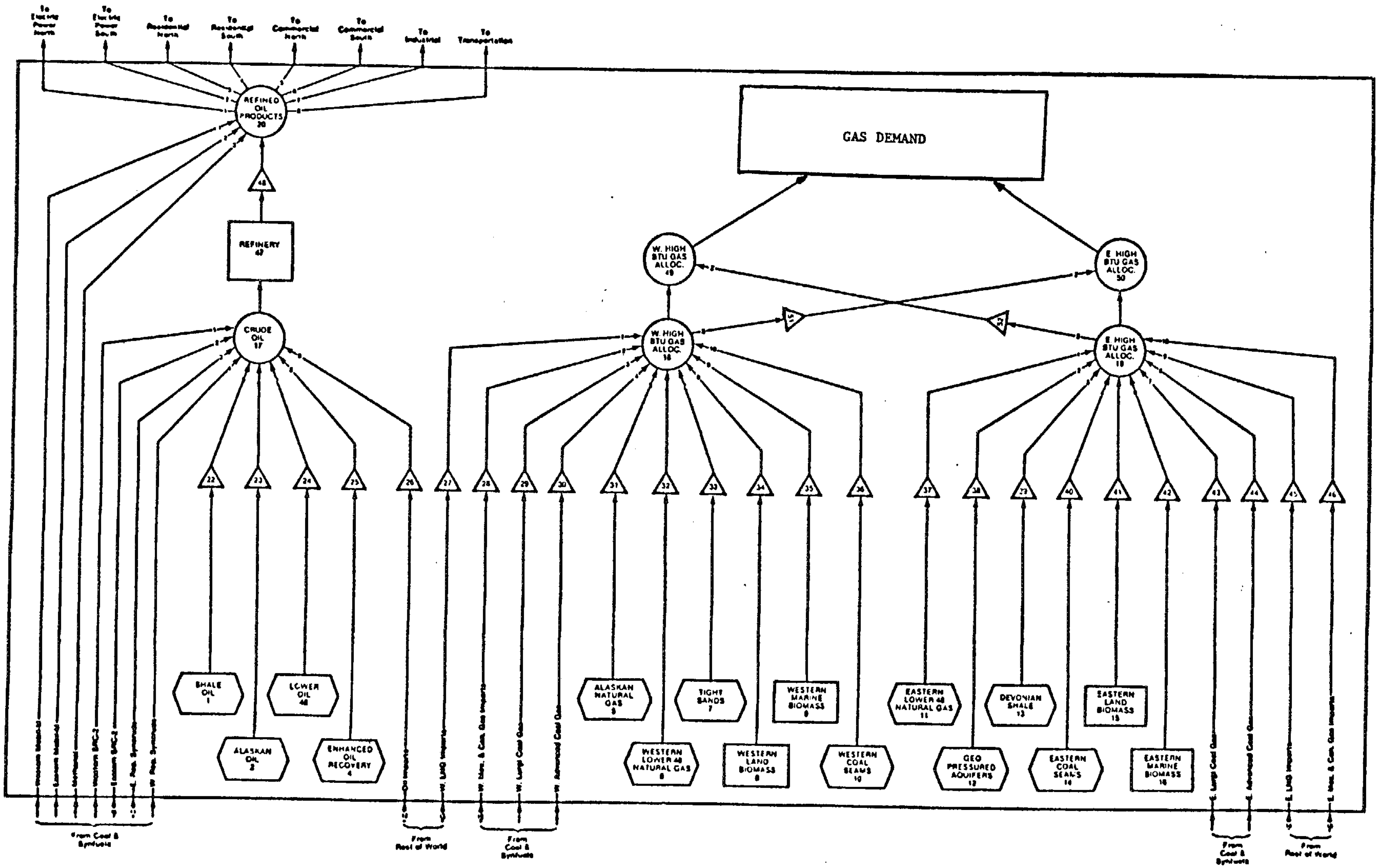
To compute the economic benefits of marine biomass R&D at GRI, we must compute the prices, quantities, and factor bills that will occur in the energy system under each of the six scenarios enumerated in the tree in Figure 1. These calculations have been made using a detailed regional representation of gas, oil, coal, electricity, and other technologies that comprise the United States energy system.

For purposes of this evaluation of marine biomass, the most important sectors of the energy system are the oil and gas producing sector (which is represented in network form in Figure 2) and the coal and synthetic fuels sector (which is represented in network form in Figure 3). Within those sectors, the portions which are particularly relevant to this analysis include all but the crossed out section of Figure 2 and none but the heavier-lined sections in Figure 3. As can be seen in Figures 2 and 3, the model represents the competition among all major gas sources including conventional gas from the lower-48 and Alaska, four types of unconventional gas, marine-and land-based biomass, imported LNG, imported gas from Mexico and Canada, and both Lurgi and advanced coal gasification. The various gas sources are further distinguished by geographic region (east versus west) where appropriate. The triangles in the figures represent long distance pipeline transmission from various sources to representative distribution centers in each demand region. Interregional gas movements, if economically warranted, will occur as shown near the top of the network in Figure 2.

The two sectors in Figures 2 and 3 are connected to a comprehensive, multisector representation of the electric generation and end use consumption sectors of the U.S. energy system. It would be straightforward (but more expensive) to compute equilibrium in the large integrated model for each of the six scenarios. However, based on previous analyses for

Figure 2.

OIL AND GAS SECTOR
(SECTOR #11)



COAL AND SYNFUELS SECTOR
(SECTOR #10)

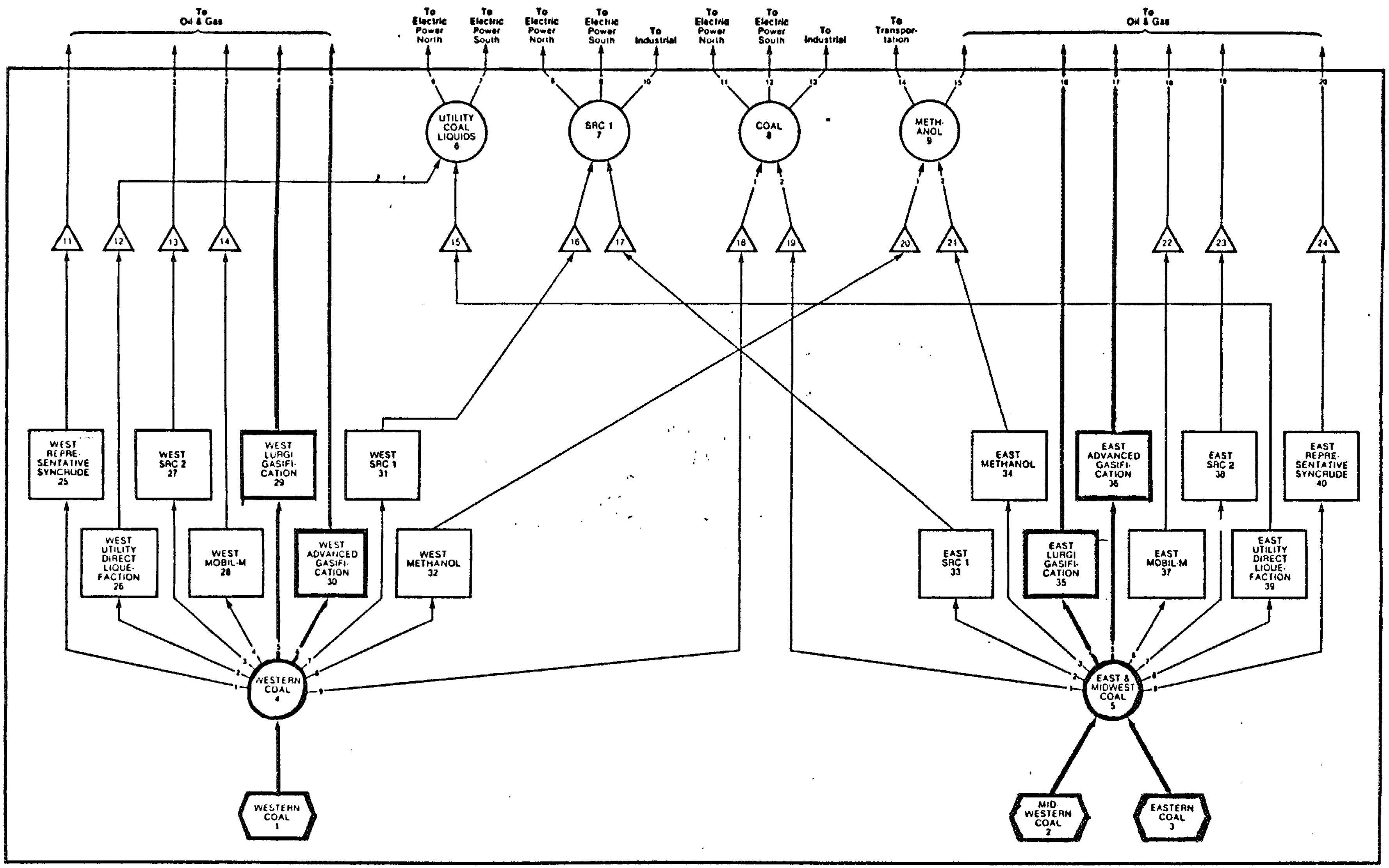


Figure 3. Coal Gasification Portion of Coal and Synfuels Sector

GRI,* it is not necessary to carry all this detail on the demand side in order to evaluate supply technologies. Rather, it is much more prudent to describe gas demand using a simple, price-sensitive demand function which has been calibrated to the large multisectoral model of electric generation and all end use sectors. In Figure 2, therefore, we have indicated at the top of the diagram a gas demand process, which contains a price-sensitive demand curve for gas from the production sectors. This gas demand process represents in an approximate but accurate fashion the response of the rest of the energy system to a change in gas price.

The gas demand process has been approximately calibrated to the gas demand projection from the GRI baseline scenario. Specifically, the baseline gas demand projection serves as a "reference" demand. This reference level of gas demand is associated with a corresponding "reference" gas price over time, which is the equilibrium gas price computed by the gas supply model in Figures 2 and 3 necessary to satisfy the reference gas demand. We emphasize that the reference gas price projection is not the GRI baseline gas price projection. Given the reference gas quantity and price, a short and a long run price elasticity have been specified to describe how this reference demand will vary if gas prices vary from the corresponding reference gas price. These elasticities have been estimated to approximate the behavior of the large model of the electric and end use conversion sectors.

Having specified the gas supply and demand structure in network format as shown in Figures 2 and 3, the model determines the most economic supply technologies that balance supply and demand over the time period from 1980 through 2025. The choice among gas technologies is based on cost comparisons, resource availabilities, market inertia, and other issues described in [4] and [5].

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*See [1].

Results

Annual production levels of gas by source for each of the six scenarios are given in Tables 4-9. Table 10 gives the level of marine biomass gas production for each of the six scenarios. The table further gives cumulative marine biomass gas production through the year 2025. In Figure 4, we have appended these cumulative marine biomass production figures to the terminal branches of the decision tree in Figure 1. We shall use the tree in Figure 4 to compute the PAM criterion "gas provided" for the marine biomass program area.*

We use three measures of economic benefits: direct consumer benefits, indirect consumer benefits, and overall economic benefits. Direct consumer benefits, commonly known as "consumers surplus," is a measure of consumer benefit that considers both the price reduction and the increased consumption due to successful R&D. Indirect consumer benefits account for changes in:

- lease bonuses and royalty payments from producers to the government,
- taxes paid by producers and pipeline companies,
- after-tax profits earned by producers and pipeline companies.

The indirect benefits correspond to the difference between the gas bill (which includes all taxes, lease bonus payments, royalties, and profits) and the factor bill (which includes only the true economic cost of the gas). What we call indirect benefits is often called "producers' surplus," but we have not used that term here because a significant portion of these benefits accrue directly to consumers rather than to producers.

Overall economic benefit is defined to be the sum of direct and indirect benefits. It is the most complete measure of the economic benefits of R&D because it accounts simultaneously for the impacts on consumers, producers, and the government. The definition of the overall

*The calculations, which are summarized in the tree, are described in the next subsection.

Table 5

Scenario 2 Model Results

SOURCES OF GAS -- NATIONAL

AF= SUM GSS= QUANTITY		TIME 1980	1985	1990	1995	2000	2005	2010	2020	2025
SOURCES OF GAS		1	2	3	4	5	6	7	8	9
L48 NAT GAS	1	19.65	19.88	18.51	15.82	12.83	9.90	7.81	4.60	3.21
ALASKAN GAS	2	0.00	0.26	0.88	1.23	1.27	1.28	1.27	1.25	1.23
LNG IMPORTS	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEX/CAN IMPORTS	4	1.00	0.65	0.43	0.29	0.20	0.14	0.11	0.05	0.03
TIGHT SANDS	5	0.00	0.05	0.22	0.60	1.14	1.51	1.49	1.02	0.78
DEVONIAN	6	0.00	0.05	0.29	0.58	0.68	0.63	0.57	0.39	0.28
COAL SEAMS	7	0.00	0.07	0.32	0.57	0.66	0.63	0.56	0.36	0.26
GEOPRESSURED	8	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.13	0.15
LAND BIOMASS	9	0.00	0.00	0.00	0.11	0.58	1.52	1.88	2.84	2.86
MARINE BIOMASS	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LURGI GASIF	11	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.20	0.28
ADV GASIF	12	0.00	0.00	0.00	0.05	0.30	1.10	3.26	7.97	10.55
TOTAL	13	20.65	20.96	20.64	19.24	17.67	16.75	17.08	18.80	19.63

QUADRILLION BTU PER YEAR--WELLHEAD/MINEMOUTH

Marine Biomass: Fails
Coal Gasification: Succeeds

Table 4

Scenario 1 Model Results

SOURCES OF GAS -- NATIONAL

AF= SUM GSS= QUANTITY		TIME 1980	1985	1990	1995	2000	2005	2010	2020	2025
SOURCES OF GAS		1	2	3	4	5	6	7	8	9
L48 NAT GAS	1	19.65	20.14	18.74	15.98	12.71	9.64	7.28	4.13	2.95
ALASKAN GAS	2	0.00	0.24	0.81	1.22	1.26	1.26	1.26	1.23	1.20
LNG IMPORTS	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEX/CAN IMPORTS	4	1.00	0.65	0.42	0.27	0.17	0.11	0.08	0.03	0.02
TIGHT SANDS	5	0.00	0.04	0.22	0.59	1.13	1.48	1.45	0.97	0.70
DEVONIAN	6	0.00	0.02	0.27	0.61	0.68	0.61	0.52	0.34	0.26
COAL SEAMS	7	0.00	0.03	0.30	0.58	0.66	0.63	0.54	0.34	0.24
GEOPRESSURED	8	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.03
LAND BIOMASS	9	0.00	0.00	0.00	0.07	0.29	0.68	1.20	1.93	2.09
MARINE BIOMASS	10	0.00	0.00	0.00	0.00	0.86	2.23	4.10	7.82	9.66
LURGI GASIF	11	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.09
ADV GASIF	12	0.00	0.00	0.00	0.03	0.16	0.48	1.17	2.60	3.10
TOTAL	13	20.65	21.11	20.77	19.36	17.91	17.14	17.63	19.48	20.34

QUADRILLION BTU PER YEAR--WELLHEAD/MINEMOUTH

Marine Biomass: Advanced Technology
Coal Gasification: Succeeds

Table 6

Scenario 3 Model Results

SOURCES OF GAS -- NATIONAL

AF= SUM GSS= QUANTITY		TIME 1980	1985	1990	1995	2000	2005	2010	2020	2025
SOURCES OF GAS		1	2	3	4	5	6	7	8	9
L48 NAT GAS	1	19.65	19.66	17.97	16.05	12.90	9.84	7.46	4.28	3.07
ALASKAN GAS	2	0.00	0.24	0.69	1.22	1.26	1.27	1.27	1.24	1.21
LNG IMPORTS	3	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
MEX/CAN IMPORTS	4	1.00	0.67	0.52	0.33	0.21	0.14	0.10	0.04	0.03
TIGHT SANDS	5	0.00	0.07	0.26	0.61	1.13	1.48	1.46	0.97	0.70
DEVONIAN	6	0.00	0.12	0.46	0.59	0.63	0.57	0.49	0.33	0.25
COAL SEAMS	7	0.00	0.14	0.49	0.58	0.61	0.58	0.50	0.32	0.23
GEOPRESSURED	8	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03
LAND BIOMASS	9	0.00	0.00	0.00	0.07	0.32	0.77	1.43	2.20	2.44
MARINE BIOMASS	10	0.00	0.00	0.00	0.00	0.94	2.54	4.84	9.82	12.12
LURGI GASIF	11	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.11	0.13
ADV GASIF	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	13	20.65	20.90	20.40	19.46	18.02	17.20	17.59	19.35	20.22

QUADRILLION BTU PER YEAR--WELLHEAD/MINEMOUTH

Marine Biomass: Advanced Technology
Coal Gasification: Fails

MBS6F

Table 7

Scenario 4 Model Results

SOURCES OF GAS -- NATIONAL

AF= SUM GSS= QUANTITY		TIME 1980	1985	1990	1995	2000	2005	2010	2020	2025
SOURCES OF GAS		1	2	3	4	5	6	7	8	9
L48 NAT GAS	1	19.65	19.46	17.68	15.66	12.77	10.17	8.35	5.70	4.15
ALASKAN GAS	2	0.00	0.29	0.84	1.24	1.29	1.30	1.31	1.30	1.28
LNG IMPORTS	3	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.01
MEX/CAN IMPORTS	4	1.00	0.68	0.56	0.39	0.29	0.27	0.31	0.28	0.21
TIGHT SANDS	5	0.00	0.06	0.22	0.58	1.09	1.48	1.54	1.17	0.92
DEVONIAN	6	0.00	0.11	0.43	0.55	0.61	0.60	0.59	0.48	0.37
COAL SEAMS	7	0.00	0.13	0.45	0.55	0.60	0.60	0.56	0.41	0.31
GEOPRESSURED	8	0.00	0.00	0.00	0.00	0.01	0.05	0.24	1.18	1.53
LAND BIOMASS	9	0.00	0.00	0.00	0.18	0.94	1.81	2.87	2.95	2.97
MARINE BIOMASS	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LURGI GASIF	11	0.00	0.00	0.00	0.00	0.01	0.06	0.40	3.45	5.76
ADV GASIF	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	13	20.65	20.74	20.21	19.15	17.62	16.37	16.18	16.93	17.52

QUADRILLION BTU PER YEAR--WELLHEAD/MINEMOUTH

Marine Biomass: Fails
Coal Gasification: Fails

Table 8

Scenario 5 Model Results

SOURCES OF GAS -- NATIONAL

TIME

AF= SUM GSS= QUANTITY		1980	1985	1990	1995	2000	2005	2010	2020	2025
SOURCES OF GAS		1	2	3	4	5	6	7	8	9
L48 NAT GAS	1	19.65	20.05	18.64	15.82	12.82	9.88	7.76	4.50	3.14
ALASKAN GAS	2	0.00	0.26	0.90	1.23	1.27	1.28	1.27	1.24	1.23
LNG IMPORTS	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEX/CAN IMPORTS	4	1.00	0.64	0.42	0.28	0.19	0.14	0.10	0.05	0.03
TIGHT SANDS	5	0.00	0.03	0.20	0.59	1.13	1.51	1.50	1.02	0.77
DEVONIAN	6	0.00	0.02	0.26	0.59	0.69	0.64	0.57	0.38	0.28
COAL SEAMS	7	0.00	0.03	0.29	0.57	0.67	0.64	0.57	0.36	0.26
GEOPRESSURED	8	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.11	0.12
LAND BIOMASS	9	0.00	0.00	0.00	0.11	0.58	1.51	1.86	2.83	2.85
MARINE BIOMASS	10	0.00	0.00	0.00	0.00	0.01	0.06	0.25	0.92	1.43
LURGI GASIF	11	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.18	0.25
ADV GASIF	12	0.00	0.00	0.00	0.05	0.30	1.05	3.06	7.19	9.26
TOTAL	13	20.65	21.04	20.71	19.23	17.66	16.73	17.06	18.79	19.62

QUADRILLION BTU PER YEAR--WELLHEAD/MINEMOUTH

Marine Biomass: GE-RMP
Coal Gasification: Succeeds

Table 9

Scenario 6 Model Results

SOURCES OF GAS -- NATIONAL

AF= SUM GSS= QUANTITY		TIME 1980	1985	1990	1995	2000	2005	2010	2020	2025
SOURCES OF GAS		1	2	3	4	5	6	7	8	9
L48 NAT GAS	1	19.65	19.50	17.75	15.77	12.85	10.23	8.22	5.15	3.71
ALASKAN GAS	2	0.00	0.27	0.79	1.23	1.28	1.30	1.30	1.28	1.26
LNG IMPORTS	3	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00
MEX/CAN IMPORTS	4	1.00	0.68	0.55	0.37	0.26	0.22	0.20	0.13	0.09
TIGHT SANDS	5	0.00	0.06	0.23	0.59	1.11	1.53	1.54	1.12	0.80
DEVONIAN	6	0.00	0.12	0.44	0.56	0.62	0.61	0.58	0.42	0.32
COAL SEAMS	7	0.00	0.14	0.47	0.56	0.61	0.61	0.55	0.38	0.27
GEOPRESSURED	8	0.00	0.00	0.00	0.00	0.01	0.04	0.14	0.42	0.46
LAND BIOMASS	9	0.00	0.00	0.00	0.14	0.90	1.69	2.85	2.90	2.91
MARINE BIOMASS	10	0.00	0.00	0.00	0.00	0.01	0.15	0.82	4.34	6.68
LURGI GASIF	11	0.00	0.00	0.00	0.00	0.01	0.05	0.23	1.34	1.77
ADV GASIF	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	13	20.65	20.77	20.26	19.23	17.67	16.42	16.43	17.49	18.27

QUADRILLION BTU PER YEAR--WELLHEAD/MINEMOUTH

Marine Biomass: GE-RMP
Coal Gasification: Fails

Table 10

MARINE BIOMASS
ANNUAL GAS PRODUCTION--QUADRILLION BTU PER YEAR

	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6
1980	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.86	0.00	0.94	0.00	0.00	0.01
2005	2.23	0.00	2.54	0.00	0.01	0.15
2010	4.10	0.00	4.84	0.00	0.06	0.82
2015	5.96	0.00	7.33	0.00	0.25	2.58
2020	7.82	0.00	9.82	0.00	0.59	4.34
2025	9.66	0.00	12.12	0.00	0.92	6.68
1980-2010	25.70	0.00	29.50	0.00	0.20	2.85
1980-2025	129.00	0.00	157.65	0.00	6.85	56.20

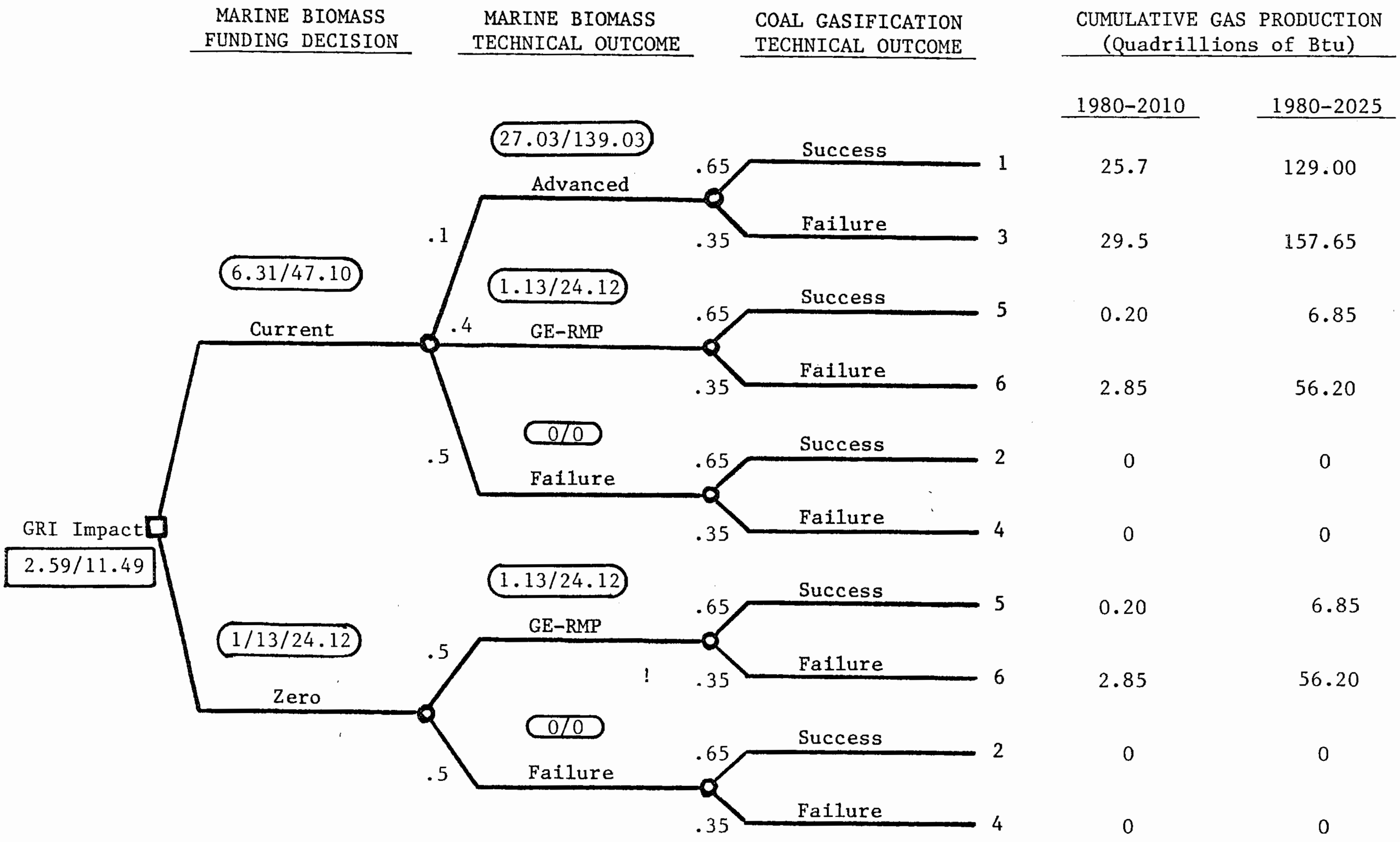

Figure 4. Cumulative Gas Production by Marine Biomass

economic benefit measure is given in detail in [3] and [6].

The present values of direct consumer benefits at 0%, 5% and 10% real rates of discount over the horizon 1980-2025 are given in Table 11. Corresponding present values of indirect benefits and overall economic benefits appear in Tables 12 and 13, respectively. For clarity, we can append these benefit figures to the corresponding end-branches of the marine biomass decision tree (as was done for gas provided in Figure 4). Figure 5 contains the decision tree describing direct consumer benefits, Figure 6 the indirect benefits, and Figure 7 the overall economic benefits. These trees can be used to calculate the benefits of successful marine biomass R&D relative to technical failure and also to determine the portion of those benefits specifically attributable to GRI's R&D activities in marine biomass. (The results of those calculations are summarized in the trees.)

Using the direct benefits tree in Figure 5 as an example, we will illustrate how the benefits calculations have been made. In this illustration, we will consider only the 5 percent discount rate--calculations for the other two discount rates are identical.

Beginning at the third (i.e., rightmost) level of the tree, we compute the expected present value of benefits in the standard fashion. That is, for each combination of funding level and marine biomass technical outcome, we multiply the corresponding benefit when coal gasification succeeds by 0.65 and add the product of the corresponding benefit when coal gasification fails times 0.35. Figure 8 shows the results of these expected value calculations for the rightmost level of the tree.

We next note that if marine biomass R&D succeeds (an event that occurs with probability 0.5), there is an 0.20 probability of a breakthrough (whose benefits are $307.41 billion) and an 0.80 probability of the GE-RMP outcome (whose benefits are $151.00 billion). Hence, we know that the expected benefit of success given current funding is simply

0.2 x $307.41 billion

Table 11

PRESENT VALUES OF DIRECT BENEFITS
(Billions of 1982 Dollars)

Scenario	Discount Rate 0%	5%	10%
1	$1409.91	$304.91	$90.83
2	895.44	186.69	53.40
3	1403.43	312.39	97.59
4	0	0	0
5	906.79	187.18	52.60
6	389.27	83.82	25.78

Table 12

PRESENT VALUES OF INDIRECT BENEFITS
(Billions of 1982 Dollars)

Scenario	Discount Rate 0%	5%	10%
1	-$537.92	-$133.90	-$48.43
2	-338.25	-82.75	-28.95
3	-528.87	-134.60	-51.01
4	0	0	0
5	-310.30	-79.35	-28.33
6	22.40	-14.10	-10.56

Table 13

PRESENT VALUES OF OVERALL ECONOMIC BENEFITS
(Billions of 1982 Dollars)

	Discount Rate		
Scenario	0%	5%	10%
1	$871.99	$170.83	$42.40
2	557.19	103.94	24.45
3	874.56	177.79	46.58
4	0	0	0
5	596.49	107.83	24.29
6	411.67	69.72	15.22

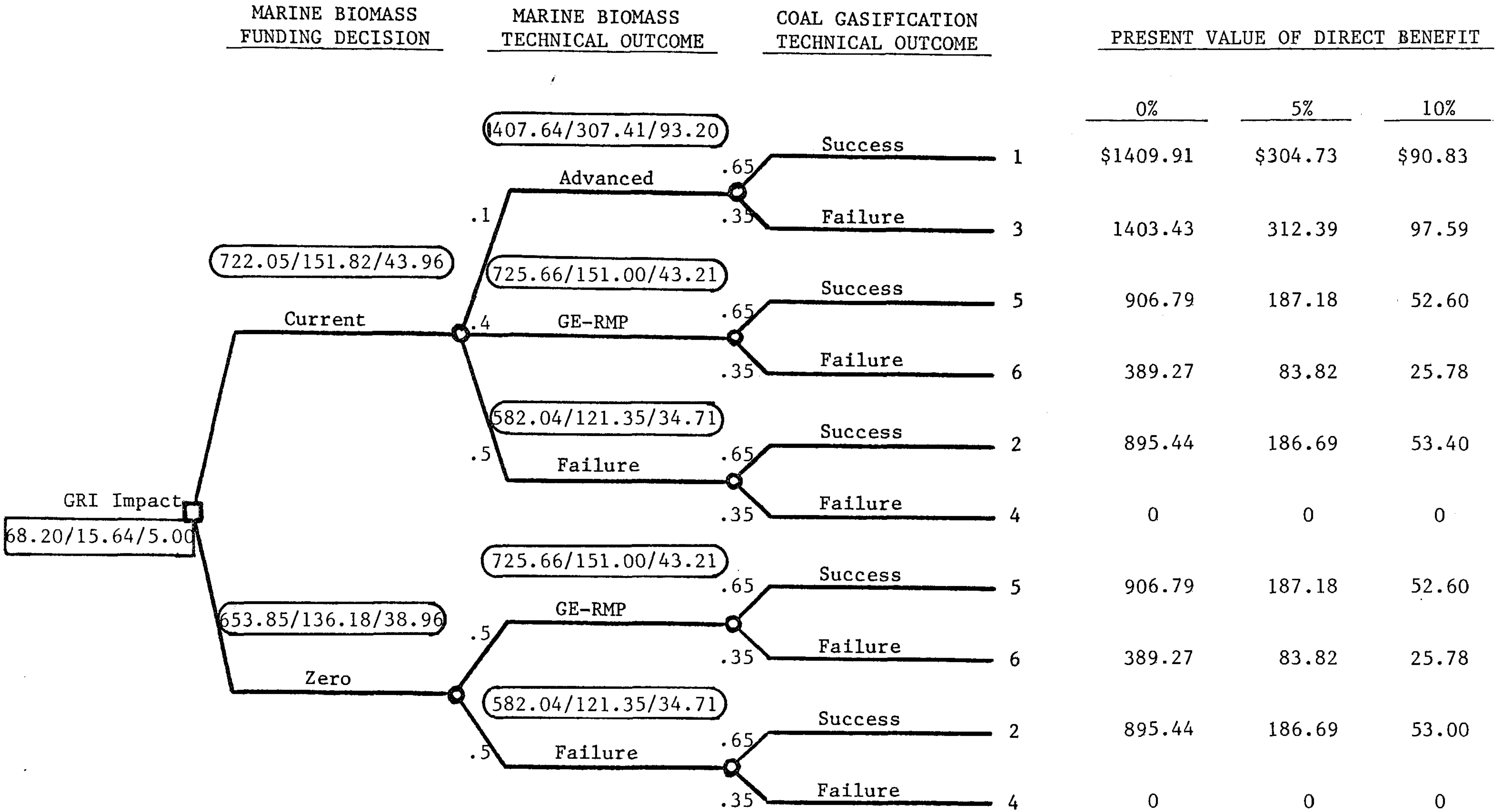

Figure 5. Direct Consumer Benerits--Marine Biomass

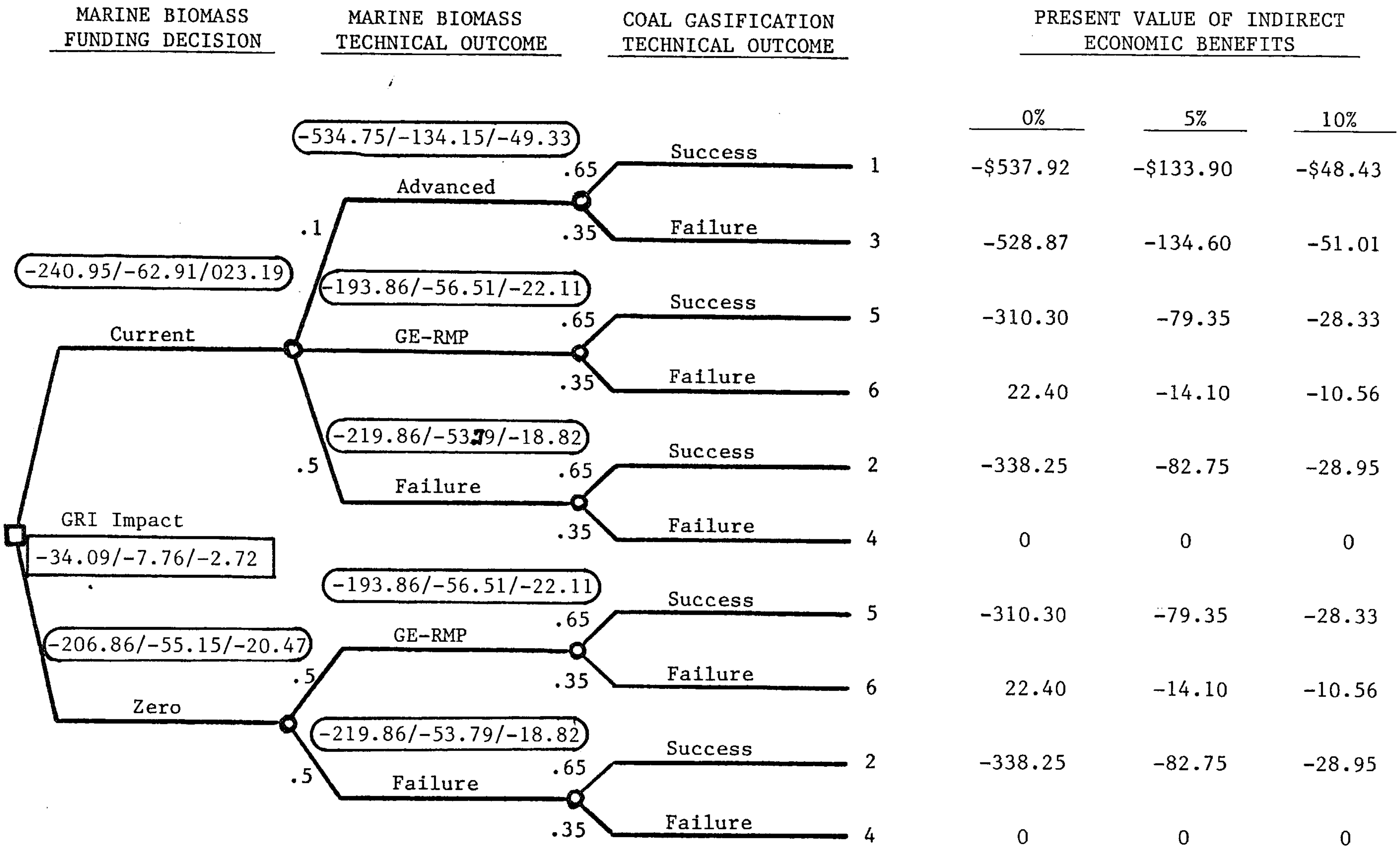

Figure 6. Indirect Economic Benefits--Marine Biomass

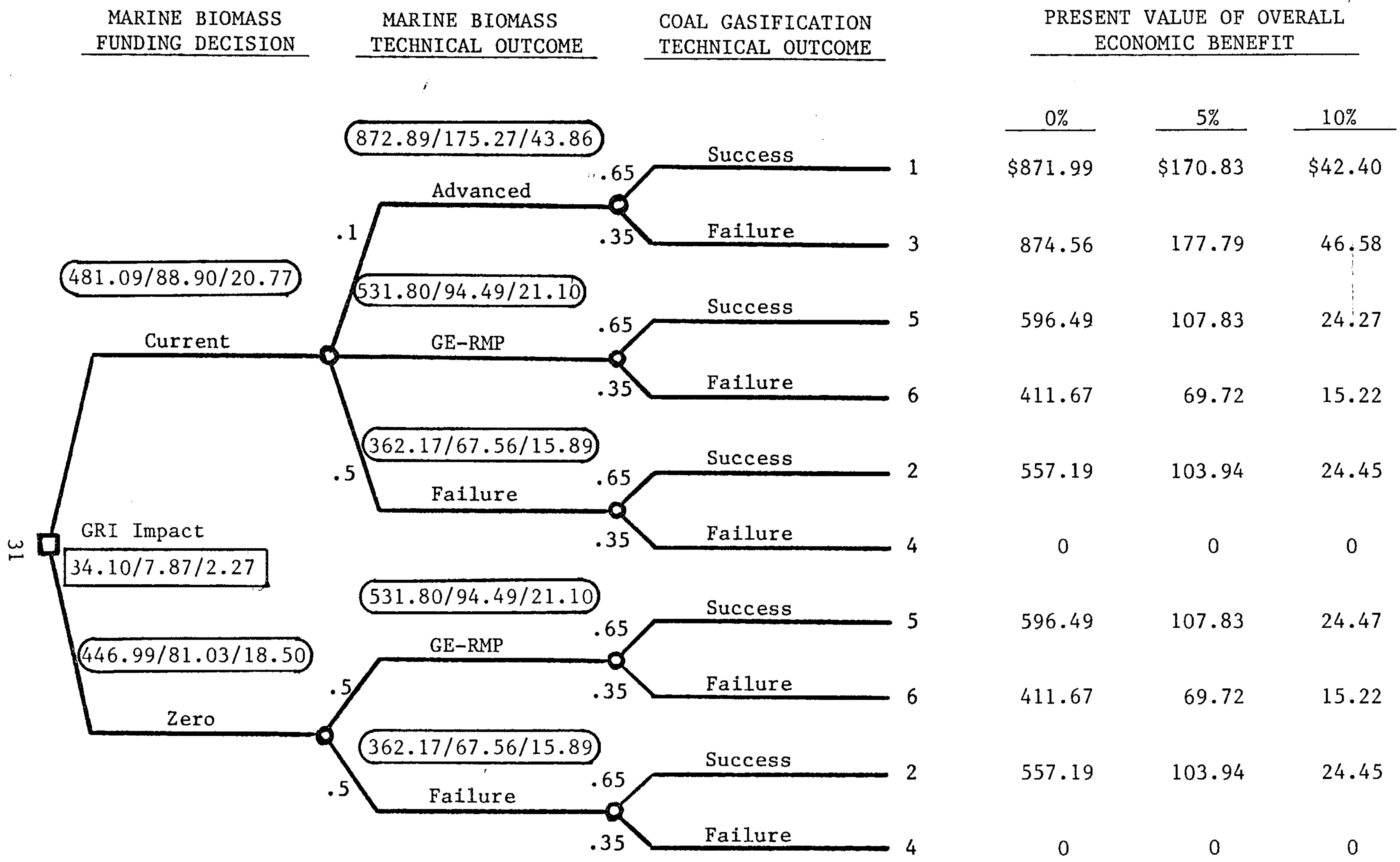

Figure 7. Overall Economic Benefit--Marine Biomass

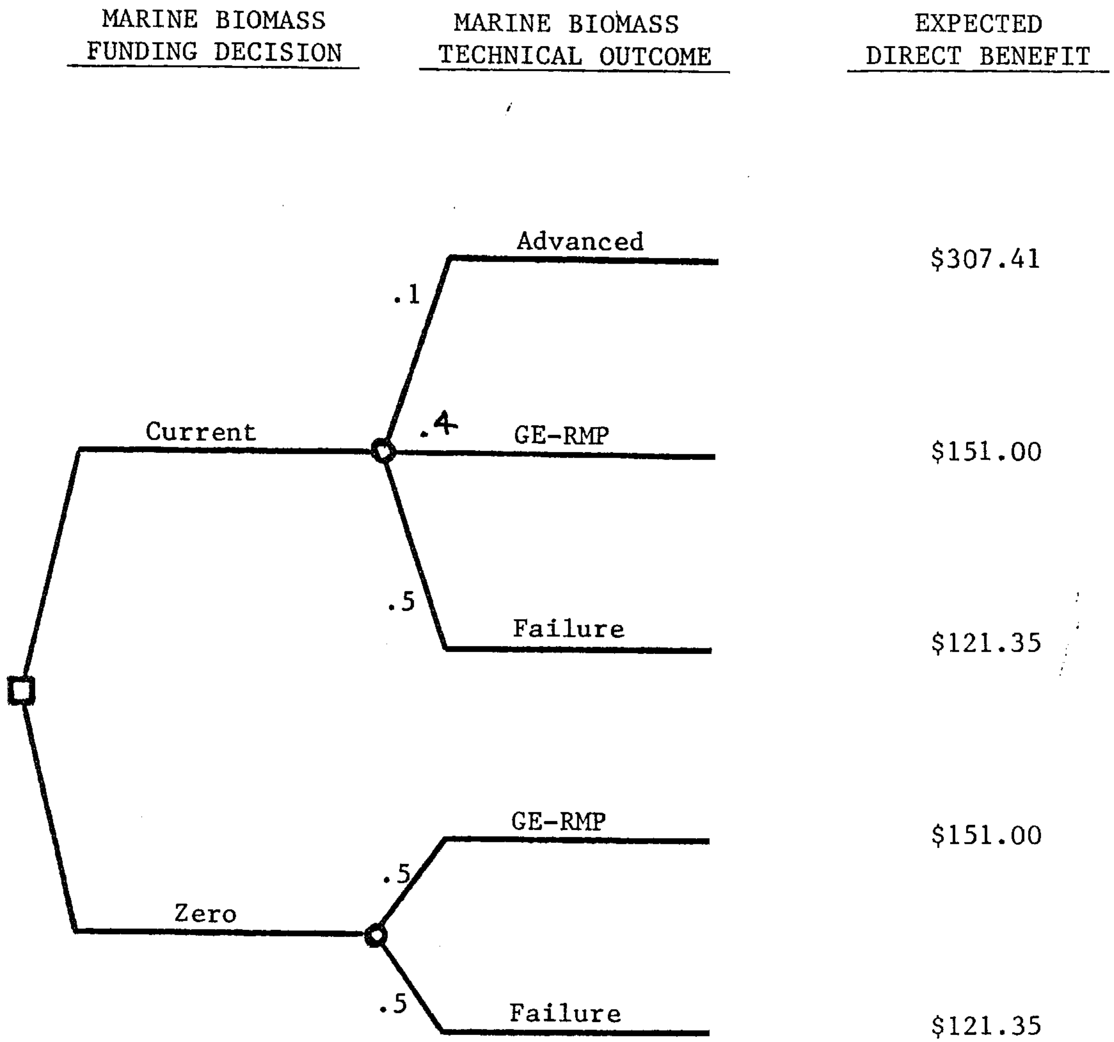

Figure 8. Expected Benefits of Marine Biomass Outcomes

+ 0.8 x \$151.00 billion

= \$182.28 billion

To determine the benefits success relative to failure of marine biomass under current funding, we compare this number with the benefits when marine biomass fails (\$121.35 billion). The difference (\$60.93 billion) represents the direct benefit of success under current funding relative to failure and is the correct input to PAM to represent current funding of marine biomass.

The first (i.e., leftmost) column of Table 14 summarizes this calculation for all three discount rates for each of the benefit measures considered. The second column of Table 14 represents the benefits of success given zero funding relative to failure. These numbers are the correct inputs to PAM to represent current and zero funding of marine biomass.

The numbers in the first two columns do not represent the incremental economic impacts of GRI's funding of marine biomass. To compute the impact of GRI's marine biomass activities, we compute the product of the benefits of success given current funding (first column) times the probability of success given current funding (0.5) and subtract the product of the benefits of success given zero funding (second column) times the probability of success given zero funding (0.5). These differences, which represent the benefits of GRI's marine biomass activities, appear in the third column of Table 14.

Interpretation of Results

The economic benefits of marine biomass R&D are significant, both in terms of the benefits of success relative to failure and the portion of those benefits specifically attributable to GRI's marine biomass program. For example, at 5% real discount rate, the present value of overall economic benefits of success compared to failure is \$42.69 billion. The expected incremental overall economic benefits attributable to GRI funding is seen to be \$7.88 billion. Both of these figures dwarf GRI's biomass R&D

Table 14

BENEFITS RESULTS FOR MARINE BIOMASS--PRESENT VALUES

Category of Benefits	Discount Rate	Benefits of Success Relative to Failure: Current Funding	Benefits of Success Relative to Failure: Zero Funding	Incremental Benefits Due to GRI Funding
Overall Economic Benefits	0% 5% 10%	$237.85 $42.69 $9.76	$169.63 $26.93 $5.21	$34.11 $7.88 $2.28
Direct Consumer Benefits	0% 5% 10%	$280.02 $60.93 $18.50	$143.62 $29.65 $8.50	$68.20 $15.66 $5.00
Indirect Benefits	0% 5% 10%	-$42.18 -$18.25 -$8.73	$26.00 -$2.72 -$3.29	-$34.08 -$7.77 -$2.72
Gas Provided	1980-2010 1980-2025	6.31 47.10	1.13 24.12	2.59 11.49

budget (or for that matter the total U.S. R&D budget for marine biomass).

As an aid to interpret the benefits results, we have converted the benefits in Table 14 to equivalent real annuities over the period 1980 to 2025. (See Table 15). The present value of the annuities in Table 15 at the appropriate discount rates are exactly equal to the present values of benefits in Table 14. Thus the annuities are interpreted as equivalent annual benefits flows realized as a result of the marine biomass R&D program, i.e., they represent the annual "payback" of GRI's marine biomass R&D. For the example quoted above, Table 15 shows that the benefits of success relative to failure under current funding and 5% discounting are equivalent to $2.40 billion per year over the entire study horizon. The expected incremental benefits attributable to GRI are equivalent to a benefit stream of $443 million per year, more than GRI's total budget for R&D of all kinds.

The magnitude of benefits from GRI's marine gas program can be further illustrated by dividing the annualized benefits in Table 15 by 20 quadrillion Btu/yr, the approximate annual gas production over the planning horizon. Making this calculation at a 5 percent discount rate, we see that GRI's marine biomass program pays approximately 2.2 cents per MMBtu on all gas consumed (not just the gas from marine biomass) in every one of the next forty five years.

Comparing the direct, indirect, and overall benefits of marine biomass R&D, we notice that successful marine biomass R&D causes negative indirect benefits to accrue to consumers. That is, the large direct consumer benefits in Table 15 are partially offset by negative indirect benefits. For example, 30% of the direct benefits of success relative to failure ($3.43 billion/yr) at 5% discounting under current funding are offset by the negative indirect benefits (-$1.03 billion per year). For the incremental GRI benefits attributable to GRI, the offset is even larger--$880 million/yr of direct benefits offset by negative $437 million/year of indirect benefits, a 50% offset. As we have mentioned previously, these negative indirect benefits result from losses in tax

Table 15

BENEFITS RESULTS FOR MARINE BIOMASS--EQUIVALENT ANNUITIES (1980 - 2025)

Category of Benefits	Discount Rate	Benefits of Success Relative to Failure		Incremental Benefits Due to GRI Funding
		Current Funding	Zero Funding	
Overall Economic Benefits	0%	$5.29	$3.77	$0.758
	5%	$2.40	$1.52	$0.443
	10%	$0.990	$0.528	$0.231
Direct Consumer Benefits	0%	$6.22	$3.19	$1.52
	5%	$3.43	$1.67	$0.880
	10%	$1.88	$0.862	$0.507
Indirect Benefits	0%	-$0.937	$0.578	-$0.758
	5%	-$1.03	-$0.153	-$0.437
	10%	-$0.885	-$0.334	-$0.276

revenues, lease bonus payments, royalties, and profits that occur as less expensive gas is introduced into the system and gas prices therefore fall.

Why are the indirect oil benefits negative? The answer, described in detail in [6], arises from a comparison of a representative technical success scenario (e.g, the breakthough scenario) and a representative technical failure scenario for marine biomass. In the success scenario, long-run gas prices are lower than they would otherwise be. As a result, the market value of natural and unconventional gas reserves are lower than they would otherwise be. Therefore, aggregate gas lease revenues and/or profits and taxes are lower than they would otherwise be. This loss in revenues is accounted for as a negative indirect benefit.

The phenomenon of negative indirect benefits appeared at a similar magnitude in the analysis of coal gasification and at a lesser magnitude in the analysis of western tight gas sands, eastern Devonian gas shales, and methane from coal deposits.* Just as with coal gasification, a substantial portion of the direct consumer benefits of marine biomass are offset by losses in lease revenues and taxes to the government and/or profits to producers. Yet, just as with coal gasification, the overall, net economic benefits after this offset is accounted for are still large relative to GRI's R&D expenditures in this area.

Before leaving this issue, we can contrast marine biomass gas--an abundant resource--with a depletable resource such as gas from western tight gas sands. A depletable source (e.g., unconventional gas) introduced in the short or mid-term (1985-1995) would not be large enough to have a major effect on the market price of gas in the time frame in which it is produced. Thus we would expect a relatively smaller decrease in the market value of natural gas leases.

By contrast, abundant sources such as coal gasification or marine biomass can have a major effect on gas prices when they begin to penetrate the market. In fact, one of these abundant sources will ultimately set the

*See [6], [7], and [8].

market price of gas. Even though none of these abundant sources promises to penetrate the market in large quantities until after the turn of the century, they nonetheless will have a proportionally greater effect on gas prices than will depeletable sources.

A major success in an abundant source such as marine biomass will lead to substantially lower gas prices and consequently lower lease values, taxes, and producer profits. Furthermore, abundant sources tend to be priced much closer to their production costs than do depletable sources. (This is particularly true if those abundant sources are the subject to rate-of-return regulation.) In addition, the increased penetration of an abundant source will displace a depletable source that would otherwise have to be used. Thus, if marine biomass R&D is successful, there are strong economic forces that:

- depress the price of gas and thereby depress lease values, taxes, and producer profits,
- depress the difference between the price and the production cost of gas, and
- displace depletable gas sources by abundant gas sources.

These forces imply that indirect economic benefits, which are driven by the difference between the price and cost of gas, are decreased by successful marine biomass R&D.

Which sources of gas are displaced by marine biomass gas if R&D succeeds rather than fails? To answer this question, we have extracted from Tables 4-9 the gas production projections in Table 16. Table 16 focuses on two years--a representative mid-term year (2005) and a representative long-term year (2025). The top half of Table 16 compares gas supplies between success and failure of marine biomass R&D given that coal gasification R&D is successful (Scenarios 1 and 2). The bottom half makes an analogous comparison but in the situation where coal gasification R&D fails (Scenarios 3 and 4).

Table 16

INCREASE IN GAS DEMAND IF MARINE BIOMASS SUCCEEDS RATHER THAN FAILS
(Quadrillion Btu/per Year)

If Coal Gasification Succeeds

	2005	2025
Natural Gas	-0.28	-0.29
Imported Gas	-0.03	-0.01
Unconventional Gas	-0.12	-0.43
Biomass	1.39	8.89
Coal Gasification	-0.37	-7.64
Net Change	0.59	0.52

If Coal Gasification Fails

	2005	2025
Natural Gas	-0.36	-1.15
Imported Gas	-0.14	-0.17
Unconventional Gas	-0.13	-2.48
Biomass	1.50	11.59
Coal Gasification	-0.05	-5.63
Net Change	0.82	2.16

Referring to the bottom half of the table, we first note that when coal gasification fails, marine biomass displaces primarily Lurgi coal gasification. If coal gasification succeeds as in the top half of the table, marine biomass displaces advanced coal gasification. In simplest terms, marine biomass displaces advanced coal gasification (if it is commercially available) or Lurgi coal gasification (if coal gasification R&D fails).

The benefits of marine biomass are determined by the cost difference between marine biomass and the particular coal gasification technology it displaces. Because the difference between the cost of advanced marine biomass and Lurgi coal gas is proportionately much larger than the difference between advanced marine biomass and advanced coal gas, we expect the benefits of marine biomass to be much larger when coal gasification R&D fails--the cost differential is much larger.

How strongly will the benefits of marine biomass R&D be stimulated if coal gasification fails rather than succeeds? To answer this question, we permute the tree in Figure 7, exchanging the ordering of the marine biomass and coal gasification technical outcomes. See Figure 9. In Figure 9, the scenario numbers and benefits measures from Figure 7 have been correctly associated with the terminal branches.

We begin by computing the expected economic benefit for marine biomass given that it succeeds given current funding. Referring to the topmost two terminal branches we see that a benefit of \$170.85 billion (Scenario 1 at 5 percent discounting) will occur with probability 0.20 and a benefit of \$107.83 (Scenario 5 at 5 percent discounting) will occur with probability 0.80 given that coal gasification secceeds and marine biomass succeeds under current GRI funding. Therefore, the expected benefit given that marine biomass succeeds under current funding and coal gasification succeeds is 0.20 x \$170.83 + 0.80 x \$107.83 = \$120.43 billion. Similarly, the expected benefit given that marine biomass succeeds under current funding but coal gasification fails is 0.20 x \$177.79 + 0.80 x \$69.72 = \$91.33 billion. (See Scenarios 3 and 6).

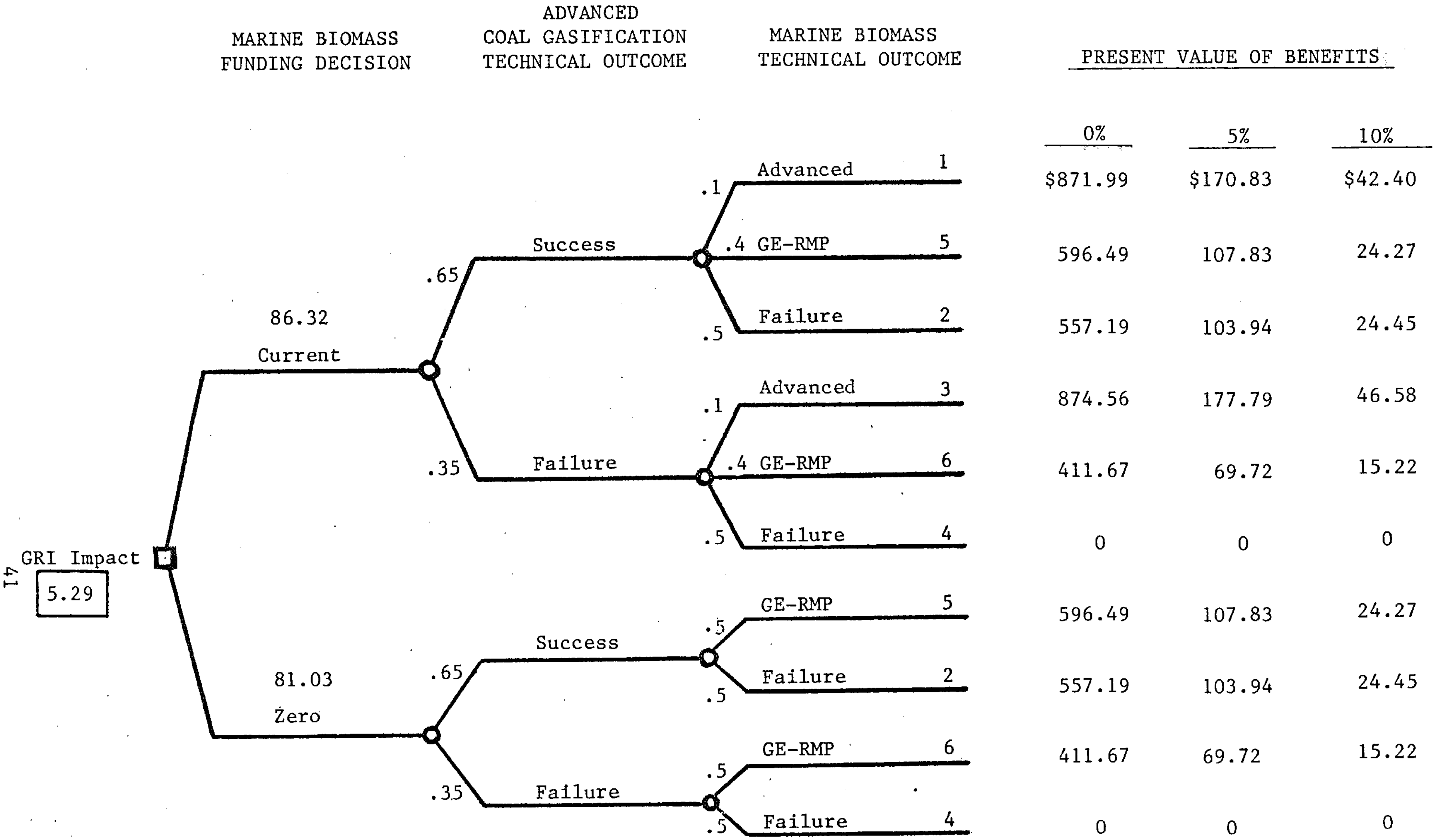

Figure 9. Overall Economic Benefits (Billions of 1982 Dollars)

We can represent Scenarios 1 and 5 in the first and second terminal branches jointly using the single benefit number $120.43 billion and Scenarios 3 and 6 jointly in the fourth and fifth terminal branches using the single benefit number $91.33 billion. (Similar calculations can be made for 0 and 10 percent discounting.)

The benefits of successful marine biomass R&D relative to failure under current funding given that coal gasification succeeds are thus $120.43 billion minus $103.94 billion (the benefits under failure in Scenario 2) or $16.49 billion. Similarly, the benefits of successful marine biomass R&D relative to failure under current funding given that coal gasification fails are thus $91.33 billion minus 0 (the benefits under failure in Scenario 4) or $91.33 billion. We have thus computed the benefits of success relative to failure of marine biomass to be 5.5 times larger ($91.33 billion versus $16.49 billion at a five percent discount rate) when coal gasification fails than when it succeeds.

We have made similar calculations for all three discount rates for both direct and overall economic benefits and tabulated them in Table 17. Note in all cases how strongly marine biomass benefits are stimulated if coal gasification R&D fails. We can illustrate the consistency between Table 17 and Table 14 by computing the expected benefit of success versus failure under current funding at a five percent discount rate. Multiplying the benefit given that coal gasification succeeds ($16.49 billion) times the probability that coal gasification succeeds (0.65) and adding the product of the benefit given that coal gasification fails ($91.33 billion) times the probability that coal gasification fails (0.35) gives the expected benefit of successful marine biomass R&D to be $42.69 billion. This is the same number given in Table 14. Of this $42.69 billion in expected value, notice that $91.33 x 0.35 or $31.97 billion occurs when coal gasification fails. In other words, marine biomas provides a "hedge" against the possible failure of coal gasification. In fact marine biomass is a textbook example of a hedge technology, paying over 75 percent of its expected benefits when its best competitor (coal gasification) fails.

Table 17

OVERALL ECONOMIC BENEFITS OF MARINE BIOMASS R&D
(Billions of 1982 Dollars)

Coal Gasification Technical Outcome	Probability	Current Funding 0%	Current Funding 5%	Current Funding 10%	Zero Funding 0%	Zero Funding 5%	Zero Funding 10%
Success	0.65	$94.40	$16.49	$3.45	39.30	$3.89	-$ 0.18
Failure	0.35	$504.25	$91.33	$21.49	$411.67	$69.72	$15.22

Referring again to Table 16, the success of marine gas actually stimulates total gas consumption in 2025 by 0.52 quads if coal gasification succeeds and by 2.16 quads if coal gasification fails. (We see the same phenomenon occurring in 2005 but to a lesser degree.) This stimulation is caused by the fact that the success of marine biomass depresses gas prices. Note, however, that when coal gasification succeeds, successful marine biomass induces a smaller percentage decrease in gas price than when coal gasification fails. Thus, in the long run, we expect to see a higher degree of stimulation of total gas production when coal gasification fails rather than when it succeeds.

How much will the benefits of marine biomass be stimulated if coal gasification fails rather than succeeds? To answer this question, we return to the overall economic benefits tree in Figure 8. Under current GRI funding, Scenario 1 gives the benefits if marine biomass succeeess, and Scenario 2 gives the benefits if marine gas fails. Using the present values of benefits at five percent, Scenario 1 pays $301.03 billion while Scenario 2 pays only $148.71 billion in benefits. The difference, $152.32 billion, represents the benefits of successful marine biomass R&D given that coal gasification succeeds. By analogy, Scenario 5 represents the benefits of successful marine biomass R&D when coal gasification fails ($218.46 billion) while Scenario 6 represents the benefits if both marine biomass and coal gasification fail ($0.00). The difference, $218.46 billion, represents the benefits of successful marine biomass R&D given that coal gasification fails.

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APPENDIX

7/15/82

Table A.1

ADVANCED HIGH BTU GASIFICATION OF WESTERN COAL
Westinghouse Process

Initial Year of Commercial Availability	1992 Success/Current Gri Funding 2000 Success/Zero GRI Funding
Nameplate Capacity of Representative Plant	9.13×10^{7} MMBtu/Yr (250×10^{6} Scf/day)
Capital Cost of Representative Plant (excluding AFUDC)	See footnote.
Initial Plant	$\$1455.4 \times 1.124 \times 1.074 \times 1.2 \times 10^{6}$ $= \$2108.3 \times 10^{6}$
Mature Industry	$\$2108.3/1.1 \times 10^{6} = 1916.7 \times 10^{6}$
Plant Stream Factor	0.90
Annual O&M Costs (excluding fuel)	$\$155.1 \times 10^{6}$/Yr
Thermal Efficiency	
Initial Plant	0.61
Mature Industry	0.68
Plant Life	20 Years
Fraction of Capital Financed by Equity	0.50

Model Inputs

$$SCC = \frac{\text{capital cost}}{\text{nameplate capacity}} = \frac{\$2108.3 \times 10^{6}}{9.13 \times 10^{7}\ \text{MMBtu/Yr}} = \$23.09/\text{MMBtu/Yr}$$

$$O\&M = \frac{\text{annual O\&M costs}}{(\text{stream factor}) \times (\text{nameplate capacity})} = \frac{\$155.1 \times 10^{6}/\text{Yr}}{0.9 \times 9.13 \times 10^{7}\ \text{MMBtu/Yr}}$$

$$= \$1.89/\text{MMBtu}$$

Note: All costs expressed in constant 1982 dollars. Navajo coal feedstock. Heating value of product = 1 MMBtu/Mscf. Capital cost has been multiplied by 1.124 as general contingency factor, by 1.074 for process development allowance, and by 1.2 to account for site specific costs. Mature industry capital costs are assumed to be 10% lower than first plant costs.

Source: GRI Westinghouse Western Coal estimates. (Evaluation of Westinghouse Gasification Process for SNG Production from Western Coal. C. F. Braun draft report, December, 1981.)

Table A.2 7/15/82

ADVANCED HIGH BTU GASIFICATION OF EASTERN COAL
Westinghouse Process

Initial Year of Commercial Availability	1992 Success/Current GRI Funding 2000 Success/Zero GRI Funding
Nameplate Capacity of Representative Plant	9.13×10^{7} MMBtu/Yr (250×10^{6} Scf/day)
Capital Cost of Representative Plant (excluding AFUDC)	See footnote.
Initial Plant	$\$1377.8 \times 1.119 \times 1.074 \times 1.2 \times 10^{6}$ $= \$1987.1 \times 10^{6}$
Mature Industry	$\$1987.1/1.1 \times 10^{6} = 1806.4 \times 10^{6}$
Plant Stream Factor	0.90
Annual O&M Costs (excluding fuel)	$\$120.6 \times 10^{6}$/Yr
Thermal Efficiency	
Initial Plant	0.65
Mature Industry	0.70
Plant Life	20 Years
Fraction of Capital Financed by Equity	0.50

Model Inputs

$$SCC = \frac{\text{capital cost}}{\text{nameplate capacity}} = \frac{\$1987.1 \times 10^{6}}{9.13 \times 10^{7}\ \text{MMBtu/Yr}} = \$21.76/\text{MMBtu/Yr}$$

$$O\&M = \frac{\text{annual O\&M costs}}{(\text{stream factor})\text{x}(\text{nameplate capacity})} = \frac{\$120.6 \times 10^{6}/\text{Yr}}{0.9 \times 9.13 \times 10^{7}\ \text{MMBtu/Yr}}$$

$$= \$1.47/\text{MMBtu}$$

Note: All costs expressed in constant 1982 dollars. Pittsburgh No. 8 coal. Heating value of product = 1 MMBtu/Mscf. Capital cost has been multiplied by 1.119 as general contingency factor, by 1.074 for process development allowance, and by 1.2 to account for site specific costs. Mature industry capital costs are assumed to be 10% lower than first plant costs.

Source: GRI Westinghouse Western Coal estimates. (Evaluation of Catalysis Research, Direct Methanation Process for Westinghouse Gasification from Eastern Coal, C. F. Braun, preliminary data, June 30, 1982.)

Table A.3 7/15/82

LURGI GASIFICATION OF WESTERN COAL

Initial Year of Commercial Availability	1986
Nameplate Capacity of Representative Plant	9.13×10^{7} MMBtu/Yr
Capital Cost of Representative Plant (excluding AFUDC)	See footnote.
Initial Plant	$\$2055.5 \times 1.123 \times 1.055 \times 1.2 \times 10^{6}$ $= \$2922.4 \times 10^{6}$
Mature Industry	$\$2922.4/1.1 \times 10^{6} = 2656.7 \times 10^{6}$
Plant Stream Factor	0.90
Annual O&M Costs (excluding fuel)	$\$189.11 \times 10^{6}$/Yr
Thermal Efficiency	
Initial Plant	0.58
Mature Industry	0.65
Plant Life	20 Years
Fraction of Capital Financed by Equity	0.50

Model Inputs

$$SCC = \frac{\text{capital cost}}{\text{nameplate capacity}} = \frac{\$2922.4 \times 10^{6}}{9.13 \times 10^{7}\ \text{MMBtu/Yr}} = \$32.01/\text{MMBtu/Yr}$$

$$O\&M = \frac{\text{annual O\&M costs}}{(\text{stream factor})\times(\text{nameplate capacity})} = \frac{\$189.1 \times 10^{6}\ /\text{Yr}}{0.9 \times 9.13 \times 10^{7}\ \text{MMBtu/Yr}}$$

$$= \$2.31/\text{MMBtu}$$

Note: All costs expressed in constant 1982 dollars. Navajo subbituminous coal. Heating value of product = 1 MMBtu/Mscf. Capital cost has been multiplied by 1.123 as general contingency factor, by 1.055 for process development allowance, and by 1.2 to account for site specific costs. Mature industry capital costs are assumed to be 10% lower than first plant costs.

Source: GRI Stone and Webster--Lurgi/Western Coal Hygas estimates. (Evaluation of the Stone and Webster Retrofit to a Western Coal Lurgi Design, C. F. Braun, June, 1982.)

Table A.4 7/15/82

LURGI GASIFICATION OF EASTERN COAL

Initial Year of Commercial Availability	1990
Nameplate Capacity of Representative Plant	9.13×10^{7} MMBtu/Yr
Capital Cost of Representative Plant (excluding AFUDC)	See footnote.
Initial Plant	$\$1979.6 \times 1.123 \times 1.047 \times 1.2 \times 10^{6}$ $= \$2793.0 \times 10^{6}$
Mature Industry	$\$279.30/1.1 \times 10^{6} = 2539.1 \times 10^{6}$
Plant Stream Factor	0.90
Annual O&M Costs (excluding fuel)	$\$244.4 \times 10^{6}$/Yr
Thermal Efficiency	
Initial Plant	0.55
Mature Industry	0.62
Plant Life	20 Years
Fraction of Capital Financed by Equity	0.50

Model Inputs

$$SCC = \frac{\text{capital cost}}{\text{nameplate capacity}} = \frac{\$2793 \times 10^{6}}{9.13 \times 10^{7}\ \text{MMBtu/Yr}} = \$30.59/\text{MMBtu/Yr}$$

$$O\&M = \frac{\text{annual O\&M costs}}{(\text{stream factor})\times(\text{nameplate capacity})} = \frac{\$244.4 \times 10^{6}/\text{Yr}}{0.9 \times 9.13 \times 10^{7}\ \text{MMBtu/Yr}}$$

$$= \$2.97/\text{MMBtu}$$

Note: All costs expressed in constant 1982 dollars. Pittsburgh No. 8 coal. Heating value of product = 1 MMBtu/Mscf. Capital cost has been multiplied by 1.123 as general contingency factor, by 1.047 for process development allowance, and by 1.2 to account for site specific costs. Mature industry capital costs are assumed to be 10% lower than first plant costs.

Source: GRI Lurgi-Eastern coal estimates. (Catalysis Research Westinghouse Eastern Coal.)