TECHNICAL
REPORT

Natural Gas and Israel's Energy Future

A Strategic Analysis Under Conditions of Deep Uncertainty

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Summary

Israel has experienced considerable growth in the past two decades. Ensuring a sufficient supply of energy, particularly electricity, to meet the ever-greater demands of a booming economy is a national concern. Israel began to introduce natural gas into its energy mix only in 2004. This report is an examination of strategic alternatives available to Israel to make greater use of domestic and imported sources of natural gas in the future. We explore both natural-gas utilization and supply-infrastructure strategies in an environment characterized by extreme uncertainty and potentially large consequences.

The project was funded by the Y&S Nazarian Family Foundation and benefited from guidance by an informal government steering committee chaired by the director general of the Ministry of National Infrastructures (MNI), the relevant ministry for energy policy in Israel. This steering committee also included representatives from the following government offices and companies:

- the Prime Minister's Office
- Ministry of Finance
- Ministry of the Interior
- Ministry of Environmental Protection
- National Security Council
- Ministry of Foreign Affairs
- Electricity Authority
- Natural Gas Authority
- Israel Electric Corporation (IEC)
- Israel Natural Gas Lines Corporation (INGL).

Although the government of Israel was not formally the client for this work nor was RAND under contract to that government, the steering committee permitted a close association between the project and the senior government decisionmakers.

The benefits we worked to derive from this project included the following:

- applications of new, computer-based methodologies to provide an analysis of how different natural-gas strategies, policies, and infrastructures might enhance the robustness[1] of Israel's energy posture despite the prevailing uncertainties

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[1] We use the word *robustness* in this instance to reflect the likelihood of any particular course of action to yield outcomes that are deemed to be satisfactory according to whatever criteria are selected for assessment across a wide range of possible

- an expandable modeling and analytical framework for energy analysis that may be further developed by RAND or others within Israel
- an examination of which factors among the many unknowns could have the greatest effect and therefore the largest influence over policy choices
- a guide for how whatever strategy may ultimately be chosen by Israel's planners may be modified in light of updated information and new circumstances
- a detailed external perspective based on objective analysis of Israel's choices that also draws from the international experience with natural gas
- a presentation of findings that are also intended to enhance the level of public discussion of issues relating to energy in Israel and with respect to natural gas in particular
- an example of a method for long-term policy analysis that may be applied in the same format to other issues of this character that Israel faces.

We conducted the analysis in two steps. In the first, we used computer modeling to search across thousands of scenarios to discover and improve strategies for the utilization of natural gas in Israel. We sought those strategies that, to the year 2030, would be low in total cost, in total emissions of greenhouse gases (GHGs), and in land-use requirements. We sought strategies that were robust enough to achieve set threshold values for these criteria across 1,265 alternative plausible future states of the world. We then applied the same process to the discovery of robust supply-infrastructure strategies for natural gas. In this instance, we searched for those strategies that would achieve low cost, avoid excessive depletion of domestic natural-gas reserves, and have low susceptibility to unmet demand in case of unintended supply cutoffs. We tested these strategies for their ability to achieve similar threshold values across a set of 5,000 different plausible futures. From this analysis, we were able to draw inferences about policy choices that would tend to enhance the robustness of natural-gas utilization and supply-infrastructure strategies.

Natural Gas In Israel

The discoveries in 1999 at the Noa and Mari-B exploratory concessions held by Delek Group consortia meant that, for the first time, Israel had discovered a significant domestic fossil-fuel supply. The government-owned INGL was established to build high-pressure gas pipelines. These first conducted natural gas to the power plants of IEC in 2004. Also, natural-gas pipeline shipments from Egypt to Israel began flowing in May 2008. Other potential sources of natural gas for Israel consist of new deepwater offshore discoveries, such as the Tamar find in January 2009 and Dalit shortly thereafter, possible further new shallow-water finds similar to Yam Tethys, importation in the form of liquefied natural gas (LNG), and possible new pipelines from other foreign sources.[2]

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future states of the world. This is in contrast to an optimal course of action that may achieve the best results among all possible plans but does so only under a narrowly defined set of circumstances.

2 LNG is often confused with natural-gas liquid (NGL), compressed natural gas (CNG), liquefied petroleum gas (LPG), and gas to liquid (GTL). The composition of LNG is distinct from these other natural-gas varieties. LNG is about 95 percent methane and 5 percent other gases. NGL is mostly composed of hydrocarbon gases heavier than methane, such as ethane, propane, and butane. LPG is 95 percent propane and butane. The composition of CNG is the same as pipeline-quality natural gas. Unlike pipeline natural gas, though, CNG is pressurized up to 3,600 pounds per square inch gauge

Natural gas is difficult to transport. Unlike petroleum and its derivatives, natural gas requires a large initial investment in infrastructure to carry it from its point of extraction to its point of use. The difficulty of transporting gas has a large role in its development and use in Israel. Natural gas is purchased by individual major Israeli customers in the power and manufacturing sectors contracting directly with the supplier. This contrasts with what has been the historical practice in most other countries, in which—at least in the early days of natural-gas use—there is one government or regulated private-sector purchase that then distributes gas to potential domestic users.

The biggest use for natural gas in Israel now and in the prospective future is in the electricity-generation system. In 2007, 69.6 percent of Israel's electricity was produced by coal, 3.2 percent by fuel oil (also referred to as *heavy oil* and known as *mazout* in Hebrew), 19.8 percent by natural gas, and 7.4 percent by diesel oil (that is, medium distillates, also referred to as *gas oil*, or *soler* in Hebrew). Plans by the government call for 40 percent of Israel's electricity to be produced eventually by natural gas.

A Framework for Weighing Alternatives Against Uncertainty

We created an analytical framework to inform many decisions that will need to be made to the year 2030, a period long enough that at least two generations of Israelis will be affected. This period is also long enough that the problem of how to deal with the myriad alternative paths the future may take is a serious concern. Therefore, our intent was to discover which strategies for natural-gas use in Israel appear most robust to uncertainties and surprises.

The logic of the analysis we present in this report is that it is not sufficient to optimize strategy for one assumed set of conditions in the presence of the deep uncertainty that surrounds long-term planning and analysis. Rather, the goal should be to seek those strategies that might not be optimal in any given future but are likely to prove robust. That is, they will achieve certain minimal criteria set by planners and the larger society across a wide range of plausible future states of the world. In this case, what we need from a model is not a prediction. As we systematically vary assumptions about factors whose future values are presently unknowable, we generate an ensemble of alternative futures purposefully constructed so as to act as a test bed for helping select among policy alternatives. In effect, we are now asking which uncertainties would affect our decisions today and how specific values of these presently uncertain factors might affect our choice among actions.

In this study, RAND researchers applied an innovative, quantitative robust decision method approach, *robust decisionmaking* (RDM), to long-term policy analysis.[3] Using the robustness criterion allows policymakers to understand more clearly the nature of their problem and the behaviors of its possible solutions. The goal is not to mechanize policy decisionmaking; it is to enhance our powers of observation and ability to draw insightful inferences.

(psig) and stored in welding bottle–like tanks. GTL is the process of converting natural gas to such products as methanol, dimethyl ether (DME), and other chemicals (Foss, 2007).

[3] More information on robust decision methods may be found, at increasingly technical levels of discussion, in Popper et al. (2005), Lempert et al. (2003), and Lempert et al. (2006). Another robust decision method is the Robust Adaptive Planning™ (RAP™) method developed by Evolving Logic.

It is convenient to categorize the components of an RDM analysis into four general classes. The first class represents the external uncertainties—the X factors outside the control of the planner or decisionmaker. The second group contains those factors that are under control by different government bodies and other actors in Israel—levers, or L factors. The third is the class of different measures (M factors) used to determine how closely the outcomes produced by candidate strategies under particular assumptions about future conditions come to meeting policy goals and criteria for goodness. The final set is the relationships (R factors) that tie the first three together. These represent either formal or informal models of cause and effect that determine how different actions taken in varying circumstances will lead to the outcomes they do.

Table S.1 might be viewed as a capsule summary of our report. It lists the factors that are specifically explored in the analysis to follow.

Predictions are not our end goal in an arena in which reliable prediction is not credible. Realizing that we cannot be sufficiently predictive, we seek some means to understand how we can choose today's actions most wisely in light of our long-term objectives. In this case, what we need from a model is not a prediction. We use a model to encapsulate our understanding of how the world works and to vary systematically the assumptions about factors whose future values are presently unknowable. This generates a large set of alternative futures purposefully constructed so as to act as a test bed for helping select among policy alternatives.

To implement this mode of analysis and apply it to Israel's choices about natural-gas use, this project built an entirely new analytical environment. We did so by using and integrating three different simulation models to analyze Israel's energy system. We then placed them within a software environment designed to support and automate the large numbers of simulations required. Figure S.1 provides a conceptual overview of the relationships between these models.

The three simulation models are the Model for Analysis of Energy Demand (MAED), the Long-Range Energy Alternatives Planning (LEAP) system for which we built a detailed model of Israel's energy economy, and the Wien Automatic System Planning (WASP) package. CARs™ is a computer program that automates operation of the simulation models and facilitates large numbers of simulations.[4]

Finding Robust Strategies for Natural Gas

We formed candidate strategies to be evaluated by considering the outcomes they produce when applied to each future state of the world in our test set. This produced a set of detailed scenarios. When we compare such results from all strategies, we may then draw conclusions about the relative strengths and weaknesses of each compared to the alternative strategies.

Each candidate strategy we used for evaluation of alternatives was framed in the form of a set of rules. In circumstances in which change is required but insufficient information exists to make modifications based on concrete analysis (as is most often the case in the real world), rules of thumb play a large role. Therefore, we constructed our strategies around such rules. Our approach was to craft an initial set of rather simple, rule-based strategies; simulate the scenario outcomes of these strategies; and then use these results to modify the strategies by adding

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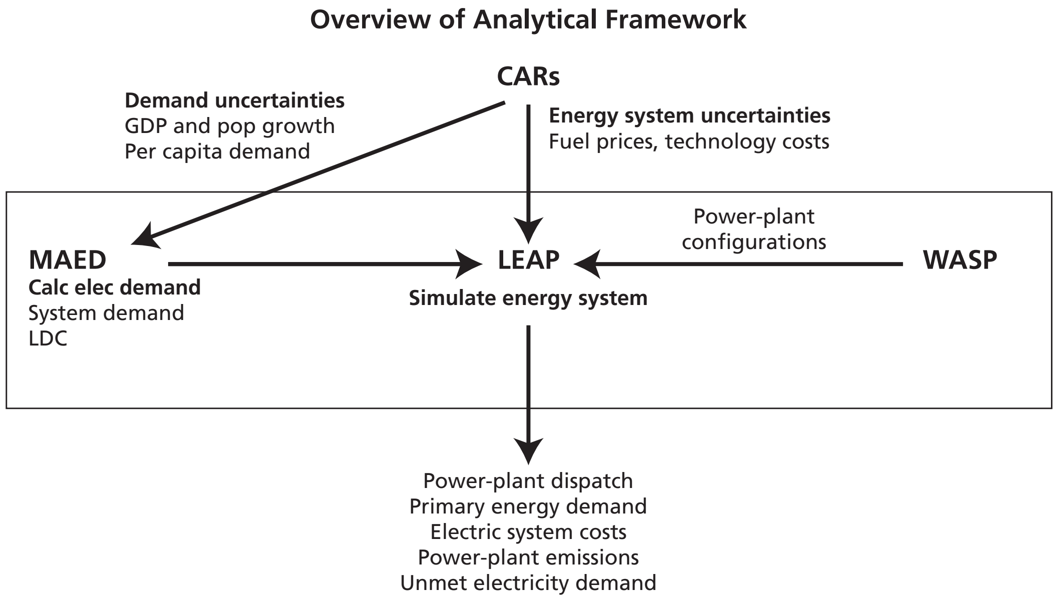
4 The CARs software was developed by Evolving Logic, which provided access to it for this study.

Table S.1
Uncertain and Variable Factors Explored in This Analysis, Arranged by Factor Type

Factor Type	Description	Factors
X	Exogenous (outside of decisionmakers' control)	Price path for coal Price path for natural gas Cost of carbon dioxide (CO_2) emissions Cost of fossil-fuel technology Cost of non–fossil fuel technology Availability of non–fossil fuel technology Demand for electricity Cost of efficiency improvements Administrative limits on GHG emissions Cost of capital Supply from foreign pipelines Discovery of new domestic reserves Fixed cost of LNG installation Variable cost of LNG supply Fixed cost of new domestic natural gas Variable cost of new domestic natural gas Cost of storage capacity Cost of capital
L	Levers (within decisionmakers' control)	New plant type and primary fuel National infrastructure construction Level of reserve generation capacity (policy) Share of generation capacity from coal and nonfossil fuel (policy) Dispatch order of electricity generation Administrative control of GHG emission levels Administrative control of land use Imposition of price on carbon emissions Adoption of non–fossil fuel technology and capacity Energy-efficiency enhancement Target level of reserve capacity Rate of domestic reserve depletion Level and timing of LNG capacity Fuel storage types Fuel storage levels
R	Relationships among factors	WASP package MAED LEAP system RAND natural-gas supply model
M	Measures used to gauge success	Total system costs Total fuel costs Balance of cost-sharing over generations Annual natural-gas supply requirement GHG emissions Land-use requirements Level of reserve generation capacity (actual) Share of generation capacity from coal and nonfossil fuel (actual) Depletion of domestic reserves (actual) Cost of providing a given level of supply insurance Cost of implementing supply insurance Potential unmet demand for electricity

NOTE: Each list of factors is divided into two sections. The first section of each list corresponds to the first of our two main research questions: What is a robust strategy for the utilization of natural gas in Israel through the year 2030? These pertain to the discussion presented in Chapters Five and Six of this report. The second section of each list is factors that are key to finding answers to the second question: What is a robust strategy for ensuring the supply of natural gas at the levels required to support the chosen utilization strategy? This question is treated in a separate analysis of natural-gas supply security that is presented in Chapter Seven.

Figure S.1
Conceptual Diagram of Main Model Modules Operating Within the Computer Assisted Reasoning System Environment



NOTE: GDP = gross domestic product. CARs = Computer Assisted Reasoning® system. LDC = load-duration curve.
RAND *TR747-S.1*

more sophistication and introducing new strategy types. Those strategies whose results were completely dominated by the results of others were dropped from the set.

We went through several generations of strategies following these basic forms:

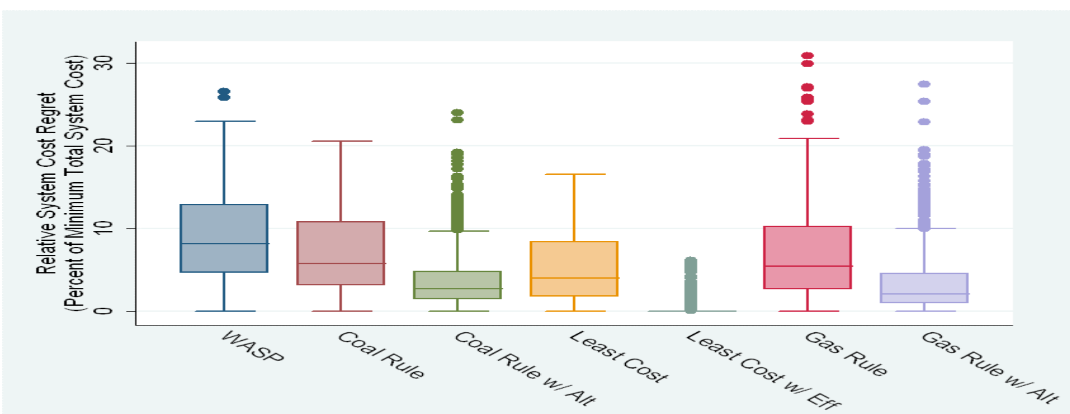
- *WASP Strategy.* This strategy serves as our reference strategy. It is an energy plan that emerges from the WASP optimization-model program when it is given a set of assumptions on demand and costs that correspond to the planning assumptions used by the MNI. As such, it alone among the candidate robust strategies is not rule based and was never modified.
- *Coal Rule Strategy.* The essence of this strategy is to carry forward a program that will add new coal-fired generating plants to provide the electricity base load for reasons of cost, the relative certainty of primary-fuel supply, and the need to ensure that the integrity of the national grid is maintained. Natural gas–fueled facilities are also added and assumed to be used during those times and conditions when it is economically efficient to utilize natural gas.
- *Least Cost Strategy.* When observation of reserve margins and peak power percentages triggers a new plant building decision, the strategy's algorithm will observe the relative cost of the available generating technologies—coal, natural gas, and solar thermal (as well as pumped storage)—and choose the one that produces electricity at the least cost.
- *Gas Rule Strategy.* Like the Coal Rule strategy, Gas Rule uses the reserve margin and fraction of peak power capacity as triggers to add new capacity. It does so by adding natural gas–fueled combined cycle (CC) plants (NGCC plants) and combustion turbines (CTs) but includes an option to build one new coal plant if the cost of building and operating a coal plant is less than that for an NGCC plant.

These basic-form strategies were varied by setting triggers (e.g., caps on GHG emissions, desired share of generation coming from coal) using different sensitivities to components of costs; varying the level of costs that triggered shifts between generation technologies; employing alternative, nonfossil fuels; determining whether policies to enhance efficiency were employed to reduce demand; and so forth.

The main test suite of alternative strategies included the WASP reference strategy and two detailed forms of each of the three other types. Each of these seven strategies was applied to 1,400 alternative specifications of future conditions (e.g., natural-gas prices, electricity-demand growth, cost of alternative non–fossil fuel technologies) This yielded a set of 9,800 detailed scenarios tracing development of Israel's electricity-generating sector through the year 2030. We examined the results from several perspectives. Figure S.2 shows the distribution for each of the strategies of the 1,400 results in terms of present value (PV) of total system costs in the period 2021–2030, when there is a good deal of variation in the energy infrastructure that will have resulted from applying the strategy. The midpoint of each box is at the median value among the full 1,400 for that strategy. The vertical axis shows the regret for following the particular strategy under the individual scenario conditions. This is the difference between the actual outcome (in this case, the net PV of total costs for the last decade in the analysis period) and the least-cost outcome (that is, the result we would have achieved if we had complete foreknowledge of future conditions and had therefore applied the optimal strategy for those conditions).

Except for several outlier scenarios, the WASP strategy has the highest mean relative system-cost regret, followed by the regret plot resulting for the Gas Rule strategy. Those scenarios that would favor the former would be unfavorable to the latter and vice versa. Those strategies

Figure S.2
Relative System-Cost Regret (PV) of Candidate Strategies, 2021–2030



NOTE: Coal Rule_Alt = Coal Rule strategy with alternatives. Least Cost_Eff = Least Cost strategy with efficiency. Gas Rule_Alt = Gas Rule strategy with alternatives. A box-plot chart is read by viewing the horizontal rule within each box as marking where the median value (50th percentile) in the distribution falls. The upper border of the box is set at the value that corresponds to the 75th percentile, while the lower border of the box is set at the 25th percentile. The whiskers extending above and below the box (if any) incorporate the points of the distribution that are furthest from the median value that fall outside the interquartile range described by the bounds of the box. This line is extended up to 1.5 times the length of the interquartile range from the closest box border. Any points of the distribution that lie beyond this whisker extension would be plotted individually as outliers.

RAND *TR747-S.2*

that include possibilities for demand-efficiency enhancements and the use of alternative generation technologies have the lowest regret, both relative and absolute, in general.

Figure S.3 shows natural-gas demand in the year 2030 in billion cubic meters (BCM) of natural gas per year. The current domestic supply source will become depleted in the early part of the next decade. The median value for all of the strategies is well above the 7-BCM capacity of Israel's current sole foreign-source pipeline, so, in the majority of scenarios, Israel would need to develop additional supply from newly discovered domestic sources, a new international pipeline for supply from some other country, or LNG facilities to make up the balance.

The simulations track pollutants emitted during the course of a year from each generation plant. Figure S.4 shows, in aggregate, the scenario outcomes for emission of GHGs. The range of outcomes is wide indeed. In some scenarios, in which there is no price attached to CO_2 emissions, increases approach 250 percent greater than the 2005 emissions in futures, in which coal is quite inexpensive. A broad finding from this result, particularly when compared to the cost-regret outcomes, is that it is not possible to look at any single metric to evaluate the relative performance of alternative candidate strategies. Each has positive behavior according to some measures while registering more-disappointing performance in others. This having been said, those strategies incorporating efficiency-enhancement measures and the possibility for use of non–fossil fuel technologies generally show less problematic outcomes across the various performance measures than do the others. This is despite being vulnerable to the additional uncertainty of the (possibly high) cost for achieving these efficiencies and employing the alternative fuel technologies.

Seeking a Robust Course for Israel

The analysis showed that strategies vary in vulnerability to certain conditions and that they have different relative strengths with respect to performance criteria of importance to Israel.

Figure S.3
Annual Natural-Gas Demand in 2030

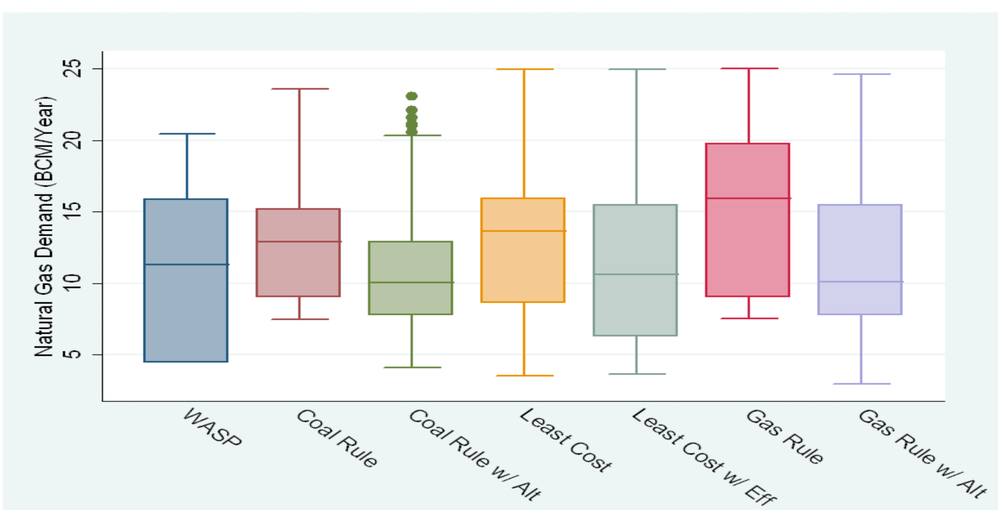


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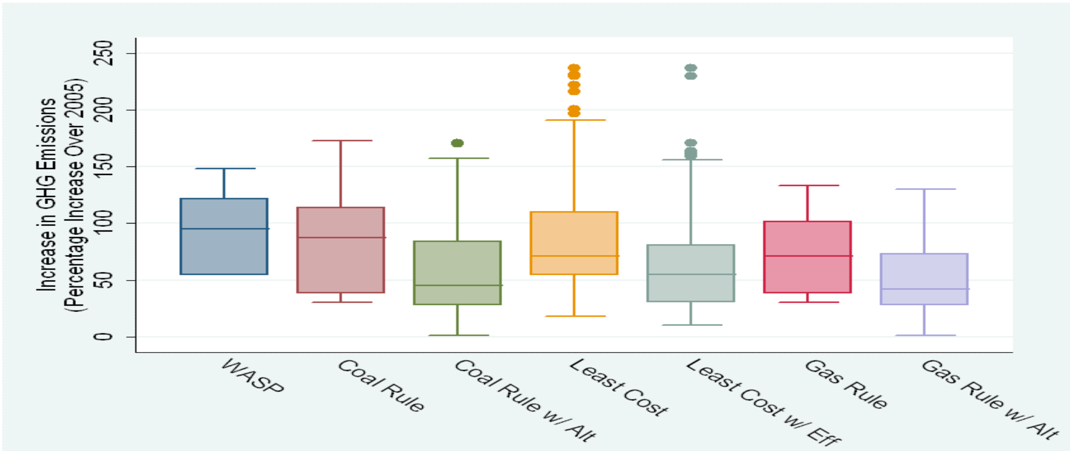
Figure S.4
Increase in Greenhouse-Gas Emissions in the Year 2030 over 2005 Levels



RAND *TR747-S.4*

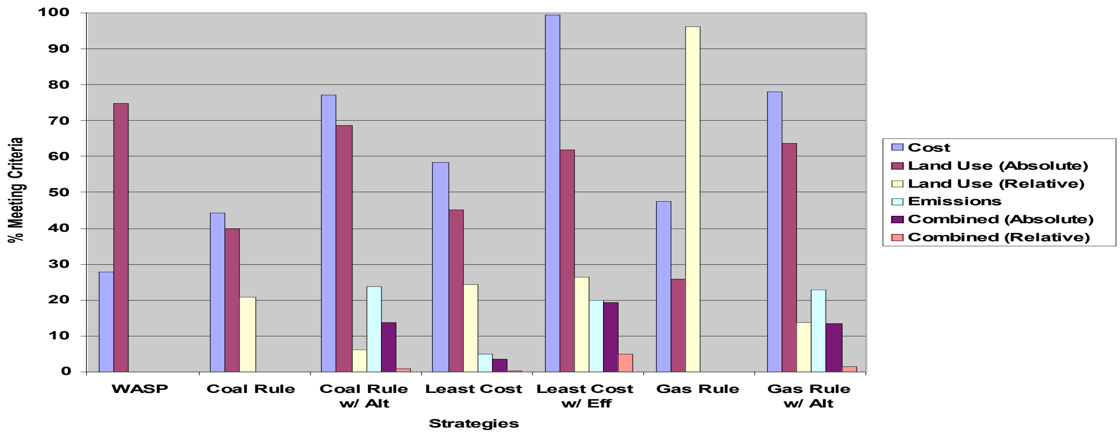
No one strategy unambiguously dominates the others. We therefore identified threshold values of what would be acceptable with respect to three important measures:

- *System Costs.* If the regret of a scenario outcome with respect to PV system costs in the last ten years of the study period (2021–2030) is within 5 percent of the costs for the zero-regret strategy or strategies, then this is considered an acceptable outcome.
- *GHG Emissions.* Our analysis shows that it would be difficult and would require extraordinary circumstances for Israel to cease the increase of its GHG emissions over the term of this study. If a scenario yields an outcome of GHG emissions by 2030 no more than 25 percent greater than the emissions recorded in 2005, the last year for which we had complete information, it is deemed successful.
- *Land Use.* The land-use metric contains two criteria. The first is whether the average land use required for comparable output of electricity by the installed capacity called for in a scenario is greater in 2030 than that currently found in Israel. If so, then the scenario fails. In addition to the intensity criterion, the second criterion relates to the total size of the area actually required to support the electricity-generating infrastructure. The threshold level will be to have an infrastructure footprint no than more than 50 percent greater than the smallest footprint achieved by any strategy under the same conditions.

Figure S.5 summarizes the behavior of each strategy with respect to the criterion thresholds across the full set of test scenarios.[5] As may be readily seen, across all strategies, it is the emission criterion that leads to the greatest share of unsuccessful scenario outcomes. For the cost-threshold criterion, while the Least Cost_Eff strategy meets this criterion measure in nearly 100 percent of the scenarios, the same strategy without the demand-management component (Least Cost) does so far less frequently, in only 59 percent of the scenarios. Note

[5] We report two forms of the combined land-use criteria. In the first instance, Land Use (Relative) (and therefore Combined [Relative]) uses the relative measure of land-use footprint we have described. We also analyzed a second form that sets an absolute cap of 8,100 MW (megawatts) of new installed capacity in the form of main natural-gas power-generating plants, Land Use (CC) (and therefore the Combined [CC] result).

Figure S.5
Percentage of Scenarios in Which Each Strategy Meets Metric Criteria



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that, under the most restrictive form that combines the results for all three criteria (Combined [Relative]), in the best instance, only one strategy meets all three objectives in even 5 percent of scenarios.

Three strategies—Coal Rule_Alt, Least Cost_Eff, and Gas Rule_Alt—consistently dominate the other four strategies with respect to each of the three criteria. Interestingly, the addition of the efficiency and alternative-energy component to each of these former strategies allows them to display a higher share of success scenarios than the Least Cost strategy under the cost criterion.

There is an important point to bear in mind before drawing conclusions from these findings. These views show only an aggregate view of strategic performance by use of scenario outcomes. It would be an error, however, to look only at raw percentages as shown in Figures S.2–S.4 and draw final conclusions about robustness. To be sure, this level of analysis does provide some valuable insight into strengths and weaknesses. But the implicit assumption behind statistics such as these is that all possible future sets of conditions are of equal interest and importance. We need to move in a direction that will allow us to better understand precisely which conditions and which scenarios lead to the principal failure modes for each candidate strategy, the better to judge which strategy might best serve stakeholder interests.

We use data-mining techniques to conduct an analysis of failure conditions for each strategy. Using the results, we take the three best-performing strategies from the original set and modify them so as to perform better under conditions that would otherwise have proven challenging for the strategy in its unmodified form.

- *Least Cost_Eff (Modified).* This strategy continues to follow the Least Cost rules and employs efficiency-enhancing measures as well. However, if conditions warrant, it may choose to retire one or two coal-fired generating plants.
- *Gas Rule_Alt (Modified).* As with the Least Cost_Eff (Modified) strategy, there is now the option of retiring one or two coal-fired plants. In addition, this strategy now pays more attention to the costs of introducing alternative-fuel electricity sources before doing so.

Finally, in the year 2021, if conditions for natural gas prove too costly, the strategy ceases to employ the Gas Rule approach and instead employs the Least Cost strategy rules.

- *Coal Rule_Alt (Modified).* The strategies of the Coal Rule family by design already have a certain level of safety-valve mechanisms encoded in their operational algorithms. The only modification we have introduced is to make the decision about investing in alternative-fuel capacity cost sensitive.

Table S.2 shows the combined results of testing the three new modified strategies, as well as their corresponding unmodified forms, in each of the 5,000 test futures and applying the same thresholds we used previously.

The effect of introducing relatively simple modifications to the base strategies to permit more-adaptive behavior appears to be large. Whereas previously the base form of Coal Rule_Alt was successful in only about 2 percent of the cases with respect to all three metrics, the success rate has been enhanced sixfold after introducing the modification. The change is even more dramatic in the case of the Gas Rule–form strategy. The performance increases from about 2 percent success across all the scenarios to 36 percent. The change for the Least Cost_Eff (Modified) strategic form is less dramatic than this but still nearly a sixfold increase in success. The modified form of the Gas Rule we have tested in this analysis emerges as the most interesting candidate to form the basis of a robust approach to framing Israel's natural-gas utilization strategy.

The point is not that Israel should adopt our test Gas Rule plan as its approach to national planning for the use of natural gas. Rather, it is to demonstrate that this rather simple-minded approach within the parameters of the model we developed can meet the objective criteria set for it in nearly 40 percent of the deliberately widely ranging scenarios we have simulated. It does so with only the most limited of foresight capability and only rudimentary rules for plan switching. This suggests that a more detailed adaptive approach, adding such elements as prospective land-use planning for energy on a national level, cost tracking focusing on key elements of cost, and emission monitoring and enforcement, could be the means for constructing implementation-ready, adaptive energy solutions that would guide the utilization of natural gas and meet at least three of the four criteria we have utilized to characterize scenario outcomes.

Table S.2
Percentage of Scenarios in Which Each Modified-Form Strategy and the Wien Automatic System Planning Strategy Meet the Metric Criterion Thresholds

Strategy	Cost	Land Use (Relative)	Emissions	Combined
Coal Rule_Alt	77	7	24	2
Coal Rule_Alt (Modified)	67	21	18	12
Least Cost_Eff	99	26	20	5
Least Cost_Eff (Modified)	99	54	39	27
Gas Rule_Alt	78	14	23	2
Gas Rule_Alt (Modified)	94	96	39	36

NOTE: Red indicates that the strategy meets that criterion threshold in fewer than 10 percent of the scenarios. Orange indicates that the strategy meets that criterion threshold in 10–30 percent of the scenarios. Yellow indicates that the strategy meets that criterion threshold in 31–75 percent of the scenarios. Green indicates that the strategy meets that criterion threshold in more than 75 percent of the scenarios.

Robust Supply-Infrastructure Strategies

What level of natural-gas supply may be planned without compromising the desire to also minimize exposure to risk in the supply of this fuel? We examine what would be required to meet demand under the most natural gas–intensive strategy, Gas Rule_Alt (Modified).

We constructed a further model based on our previous analyses of Israel's future natural-gas use, the behavior and requirements of the strategies for meeting demand, and now adding the possibility of sudden shortfalls in supply. The purpose is to explore answers to three main questions:

- What infrastructure is needed to meet Israel's long-term natural-gas demand and at what cost?
- How rapid would depletion of natural gas from new domestic reserves need to be?
- How robust can Israel be to changes in future deliveries of natural gas through foreign import pipelines?

We assessed four different strategies for natural-gas infrastructure development that assume that new gas supplies could come from new domestic deepwater (DDW) sources and from an LNG terminal. The model we used is designed to be expanded to consider other sources. The DDW Only strategy tries to supply all future gas demand from such reserves. The two versions of the Joint DDW/LNG strategies simultaneously build supply capacity from the DDW reserves and construct an LNG terminal but differ in how they operate. In the Joint DDW/LNG (LNG Priority) strategy, natural gas is supplied first from the LNG terminal up to its capacity, and then any residual demand is supplied from DDW sources. In the Joint DDW/LNG (DDW Priority) strategy, the converse is true. Finally, the DDW Then LNG strategy builds capacity at the DDW reserve first up to a limit and then builds an LNG terminal when needed.

The model was evaluated for six different levels of demand over the period to 2030 by selecting specific scenarios from the test set utilized in performing the prior analyses. In each of these scenarios, the Gas Rule_Alt (Modified) natural-gas use strategy was run against a set of conditions selected to elucidate the types of infrastructure configurations needed to satisfy different levels of demand. These demand paths varied from requiring less than 7 to more than 25 BCM per year by 2030.

If the issue were only security of supply, it would not be so challenging. Costs of natural-gas supply and insurance of that supply also come into play. We again scanned across many scenarios to better understand the balance of cost and benefit. Using the RAND natural-gas supply model developed for Israel, we drew a sample set of 5,000 alternative possible future sets of conditions by varying assumptions about demand for natural gas, the fixed and variable costs peculiarly associated with fuel coming from DDW or LNG sources, the discount rate, and the amount of natural gas supplied from foreign-source pipelines. We also varied policies setting an explicit level of desired reserve capacity through different combinations of LNG and DDW investment, storage of natural gas in reservoirs, and storage of diesel as a switch fuel. We then examined the outcomes for each of the four supply strategies against each of the 5,000 alternative sets of future conditions. In doing so, we explicitly added costs of insurance to the cost of supply of natural gas.

We evaluated the outcomes with regard to several criteria and again established minimally acceptable thresholds for each:

- *Supply-System Costs.* Strategies that achieve these minimal thresholds across many alternative future states of the world and across several measurement criteria are termed as being more robust than those that fail to do so. Specifically, we set the cost threshold as being within 5 percent of the result shown by that strategy among the four that generates the lowest supply-system costs for that set of conditions.
- *Depletion of Domestic Reserves.* The threshold for DDW depletion we set at a total of 105 BCM through the year 2030.
- *Potential Unmet Demand.* For the criterion of being able to meet demand for natural gas, if the policy-specific target level for being able to replace a share of foreign supply has not been met and electricity generated from natural gas cannot be supplied at the target level, the outcome is considered a failure.

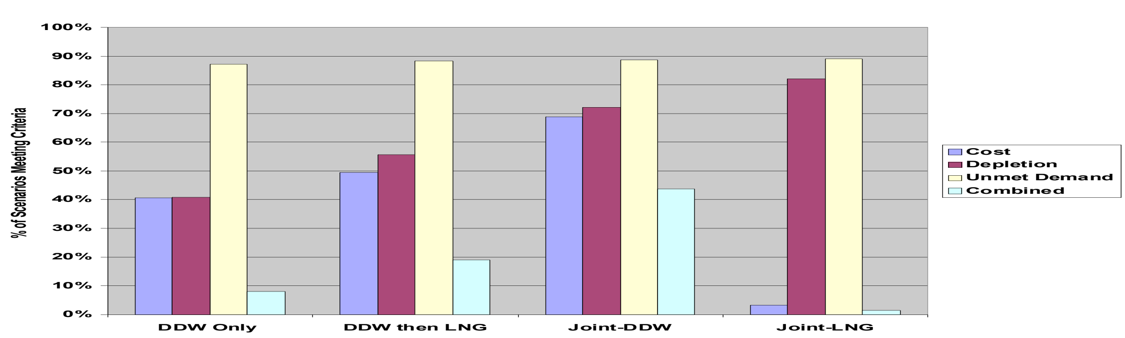
The results are shown in Figure S.6. For each of the four approaches, we calculate the share of scenario outcomes that meet the individual criterion threshold as well as the share of scenarios in which the strategy meets all three thresholds. As before, we note that this analysis treats all scenarios as being equally probable. It also does not weight the relative importance of the three criteria for assessing successful outcomes.

But, a further question yet remains. We have discussed only the costs of normal supply and for obtaining a certain level of insurance. But, if there is a need to actually make use of the supply-security assurance measures, how do the strategies compare? That is, what if Israel needed not only to pay the cost of an insurance policy but the deductible associated with each strategy as well?

To generate results, we imposed a one-year shutoff of all supplies through foreign pipeline sources in 2025. This was also the year in which several coal-fired power plants were retired under several of the demand scenarios we used for this analysis and the test bed of supply scenarios uses the Gas Rule_Alt (Modified) natural-gas utilization strategy. Therefore, the shock to supply comes at a particularly stressful time.

Further analysis makes clear that what drives both basic supply-insurance and emergency-supply costs is the ratio of costs uniquely associated with the LNG supply chain when com-

Figure S.6
Percentage of Scenario Outcomes Meeting Relative-Cost, Domestic Natural-Gas Depletion, and Supply-Reliability Criteria



RAND *TR747-S.6*

pared to those for DDW-derived natural gas. Therefore, the core issue becomes less one of how well each strategy will perform under varying assumptions about the probability of a year-long supply disruption than about how well they will perform under varying assumptions about the relative average supply costs.

This point is demonstrated in Figure S.7. It shows an expected relative regret in total cost for each strategy when faced by conditions represented by different price ratios. The choice among different supply strategies depends crucially on assumptions about the ratio between the unique costs associated with the alternative natural-gas supply sources. If cost were to be the only consideration, then choosing the Joint DDW/LNG (LNG Priority) strategy would imply a belief that the LNG/DDW cost ratio will be at the extreme low end on average. On the other hand, opting for the DDW Only approach would require holding the belief (and placing the bet) that this ratio will instead trend toward the high end of the range. Note that, if one had certain knowledge about what the price ratio would turn out to be, there is almost no level at which DDW Then LNG would be the optimal (minimum expected regret) strategy. On the other hand, if we truly did not have strong confidence in being able to predict this average ratio and instead viewed the likelihood of each value level as being uniform, it is precisely DDW Then LNG that suggests itself as a candidate robust strategy. Although it is rarely if ever the strategy that provides minimum cost under the prescribed conditions, it almost always runs second best throughout the range, and its failure tends to be more graceful in terms of cost than the other candidates.

This does not necessarily lead to an endorsement of the DDW Then LNG supply approach for Israel. There is also the question of what is passed on to future generations beyond the year 2030, the potential value of the security that comes from possessing a domestic natural-gas reserve, and the still-unresolved question of whether Israel truly would be able to draw on reserves as large as those required under some scenarios.

Figure S.8 encapsulates scenario outcomes for demand in a manner similar to that for expected relative regret with respect to cost. This time, the question is the level by which any DDW or other additional reservoirs must be depleted by 2030 if a given strategic course is followed. Whereas, in the discussion of cost differentials, it was price ratios that proved the key drivers, in this instance, it is the level of demand. We see a clear ranking of alternatives with

Figure S.7
Expected Total-Cost Relative Regret of Four Natural-Gas Supply Strategies: Liquefied Natural Gas/ Domestic Deepwater Premium Cost Ratio

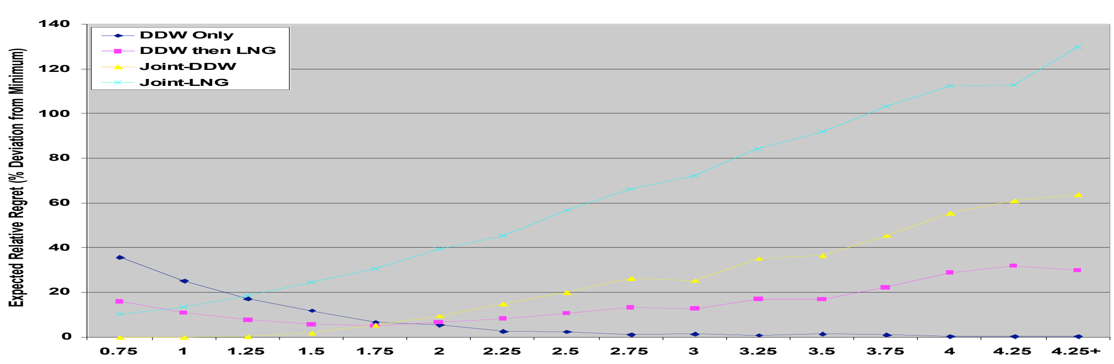


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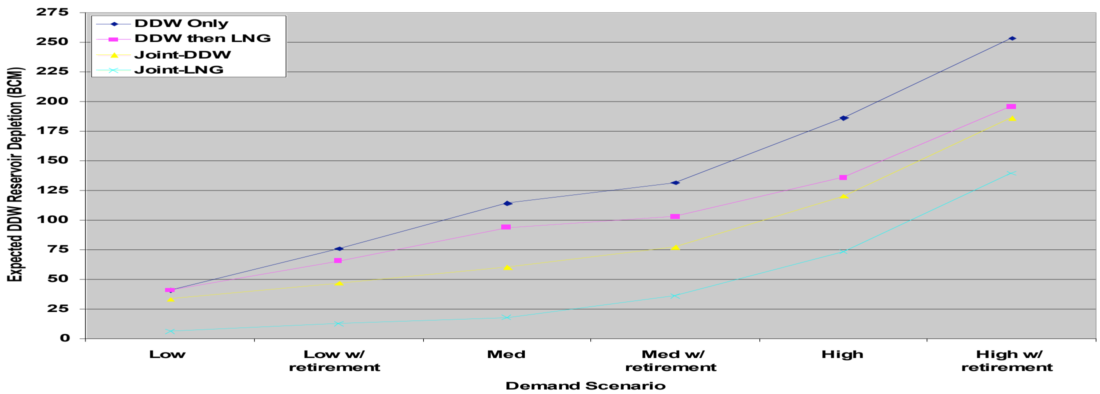
Figure S.8
Expected Domestic Deepwater Reservoir Depletion of Four Natural-Gas Supply Strategies: Level of Natural-Gas Demand



RAND *TR747-S.8*

no switches of the type we observe with respect to cost. The cost-versus-depletion trade-off is made clear when this ranking is compared with the cost trajectories shown in Figure S.7. The DDW Then LNG strategy is by no means the most favorable when measured in this dimension. Bear in mind, however, that these results are for demand scenarios evolving from the most natural gas–intensive use strategy. If we were to allow the possibility of other natural-gas utilization strategies than the one we have fixed by selecting the six demand scenarios, in the highest-demand region of this figure, the depletion would likely be tempered by the building of a second LNG installation or the construction of a coal-fired plant, depending on other circumstances.

These views provide decisionmakers with a concrete description of what the trade-offs are and what drives the differences between approaches. A political decision could be made about priorities among different objectives because, in the final analysis, the actual policy will result from political processes, political discourse, and political trade-offs. This is as it should be. What is valuable about views such as those shown in Figures S.7 and S.8 is that they provide a framework for establishing what ought to be the appropriate political trade space within which these discussions should occur.

Conclusions

As an independent research effort, we sought to develop an analytical framework that is extensible and that could be easily amplified by further input from those formally charged with the task of planning and developing Israel's energy future. Our emphasis was on tool building. In exercising these tools, we have explored what measures would be to Israel's greatest advantage in achieving a future profile for natural-gas use that reduces its people's exposure to vulnerabilities and risks. The following suggestions emerge from our analysis. These findings should not be viewed as conclusive but rather as indicative of areas for Israel's planners to explore in greater detail in exercising these tools:

- Demand management is Israel's first line of energy security.

- Israel should use current planning techniques to make decisions on capacity additions through 2015. For the period beyond 2015, a new major assessment of future demand and needs should be initiated using adaptive planning methods. Steps should be taken now to put that planning process in place.
- Israel may primarily invest in NGCC power plants, provided that sufficient supply may be ensured to fuel these plants.
- Israel should take delivery of contracted volumes of gas through its foreign supply pipeline and consider new contracts up to the pipeline's physical maximum, if this natural gas is competitively priced.
- Israel should prepare implementation (e.g., planning, regulations, design, contract formats) for an LNG terminal but could delay construction and first exploit newly discovered domestic sources.
- Israel needs to maintain a diversified mix of fuels for generating electric power. Israel should also invest in solar-thermal electric power plants or use solar thermal to preheat steam for fossil fuel–fired power plants.
- Israel's guidelines on the minimum threshold for electricity generated by coal should be reviewed to consider including other indigenously available, relatively secure means of generation, such as solar. The threshold levels should be evaluated from a total system perspective, including a more detailed study of the possibilities of load shedding at high levels of natural-gas use.
- The Israeli government should regulate the wholesale and retail prices of domestically produced natural gas on the basis of the cost of imported gas and to ensure an attractive rate of return for domestic producers.
- Israel should guard against disruptions in natural-gas supplies by storing sufficient quantities of diesel to smooth possible future supply disruptions.
- Israel should complete construction of the inland natural-gas supply pipeline, parallel to the existing offshore coastal pipeline.

The principal value this report presents is a detailed understanding of what are favorable future environments for Israel and, perhaps more importantly, what factors would lead to futures that are undesirable in light of Israel's goals and interests. We have demonstrated what actions and means would be to Israel's greatest advantage in achieving an energy future that reduces its people's exposure to vulnerabilities and risks. The following suggestions for the nation's planning process emerge from our analysis:

- Planning based on observation, well-defined priorities, and goals and that is advanced by means of rules designed to implement preapproved, flexible responses to updates in the available information can enhance robustness.
- We have quantified the dynamics of various trade-offs that planners face and provided an indication of where well-hedged positions among the various goals may be found.
- Three types of information may be developed from our findings and subsequent, more-detailed RDM analyses. These are *signposts* (indicators that may be monitored for early indications of conditions that may prove either favorable or unfavorable), *hedging* actions that provide some level of insurance against unfavorable consequences, and *shaping* actions (active measures taken to enhance the likelihood that conditions will remain or will become conducive to the plan).

Demand Management Is Israel's First Line of Energy Security

The most effective shaping action Israel could undertake is to institute policies that will enhance the efficiency of Israel's energy use. We found that almost all of the failure scenarios occurred when growth in demand was high. Even with important new discoveries of domestic natural gas offshore, the amount of this fuel required to meet demand in these energy-hungry futures raises serious questions about where the necessary fuel will come from. In addition, the relatively modest criterion for achieving success in controlling emissions of GHGs is very difficult to achieve even for natural gas–intensive strategies under high demand-growth conditions.

Data from our simulations suggest that a reduction in electricity demand that results in 1 percent less electricity consumption in 2030 will cause a 0.57 to 0.58 percent decrease in the PV of system cost between 2008 and 2030. Similarly, based on the mean estimates for the Least Cost strategy, a 1-percent reduction in 2030 electricity demand will cause CO_2 emissions to be 0.79 percent lower in 2030. Enhancing efficiency would have a large effect even on the narrower question of the level of natural-gas use for which to plan. *Steps taken to affect this factor of demand are among the highest-payoff actions that the government of Israel could take in the realm of energy policy.*

A Diversified Fuel Mix Enhances the Robustness of Strategies

The Gas Rule_Alt (Modified) strategy would potentially require the greatest supply of natural gas. But it also appears as the candidate most likely to possess the quality of robustness we had been seeking to discover. The fundamental thrust of the Gas Rule strategies is that natural gas be made the cornerstone fuel for generating electricity in Israel over the next two decades. The emphasis on natural gas in the highlighted strategy should not be understood in isolation from the rest of Israel's electricity generation and energy system. Only the heavily modified form of the strategy achieves an appropriate level of apparent robustness. This strategy presumes that Israel will adopt policies to enhance the efficiency of electricity consumption. It also presumes Israel will build the maximum level of alternative (nonfossil) fuel plants consistent with both availability and the underlying economics of doing so.

Simply to add natural-gas facilities without other measures could easily be cause for future regret. The final form of the Gas Rule that we examined implies that *Israel should seek a diverse set of primary-fuel types*. Natural gas is present in successful scenarios, but so is coal, diesel for backup and peak generation, and, importantly, as much non–fossil fuel technology as the system can take on given the realities of cost and availability. This is a point we would like to emphasize: *Implementing policies that maximize both efficiency improvements and utilization of non–fossil fuel alternatives makes as great a difference to final outcomes as any choice of base fuel.*

Accelerating the Use of Non–Fossil Fuel Alternatives Is Especially Critical for Israel

In contrast to the shaping strategy of increasing energy efficiency, diversification of fuels provides a hedge against potential risk. Our analysis shows that an indifference to costs when investing in nonfossil energy sources may lead to serious failures. But this is largely an artifact of the deliberately simplistic approach displayed in the earlier forms of our rule-based strategies. The planners for Israel are more than capable of detecting the signs that the technology and economics in the market for alternative energy are not fulfilling their hoped-for promise. We find the dangers of failing to exploit the potential of this avenue greater than the likely costs of doing so.

Natural gas will be a good fuel for Israel in meeting its needs for the immediate and longer-term future. Our analysis repeatedly shows, however, that overreliance leads to vulnerabilities in several dimensions. Israel should continue to accelerate its exploration of non–fossil fuel alternatives to provide a robust foundation to its renovated energy infrastructure.

Israel Should Plan for an Adaptive Course

It is the inherently flexible and adaptive character of the Gas Rule_Alt (Modified) strategy, more than any single element, that allows it to be successful across a wide range of future conditions. This suggests a useful approach to planning the construction of Israel's future energy infrastructure. We recommend that Israel take an approach that lays out goals and guidelines, criteria for success as well as rules for the road as short-term decisions need to be taken. Most important would be to set guidelines for the indicators that are to be monitored and the basic courses of action that will be taken depending on the values these indicators may take. Previously drafted adaptive changes may be introduced into actual energy-infrastructure build plans when conditions warrant.

As a practical matter, Israel might do well to consider a two-step approach to its planning for energy. The first step would be to plan for the period to 2015 in a traditional fashion. At the same time, a set of signposts, flexible responses, and archetypal plans would be prepared within a comprehensive planning framework. Then as 2015 (or a similar target date) draws close, these materials may be used to fashion the more-adaptive plans, policies, and procedures for the following period. This incremental approach can be further divided into smaller time periods as appropriate and comfortable within the planning institutions.

Regulatory Issues Affect Natural-Gas Planning and Are Affected by Analytical Outcomes

Our analysis focused on aggregate outcomes on a year-by-year basis. Deriving more-definitive implications for regulatory issues would require more-detailed analysis and modeling. We offer the following notes as a guide to what implications our analysis may have for discussions about natural-gas regulation.

It is clear that, in order to encourage the level of capital investments necessary to achieve the level of natural-gas use promised by recent domestic discoveries, transparent licensing and permitting regulations should be developed for exploration and production activities and building pipelines and natural gas–powered generation plants. Perhaps the most important stance by those charged with the crucial function of land-use planning in Israel is to recognize beforehand the contingent nature of much of the planning that needs to go forward from this point. In order to be in a position not only to react to previously identified signpost conditions but to exploit the opportunities they will present, it would be advisable to have in readiness the means to elaborate on basic preplans and quickly flesh them out in light of the contingencies of the future. This is not the most comfortable of positions in which a planner can find him- or herself, but being in a position to implement once the relevant signposts indicate the direction of needed response appears to be an important capability for Israel to nurture and enhance.

Israel Should Guarantee Sufficient Storage to Smooth Future Supply Disruptions in the Short Term

We have concluded that Israel can ensure that its supply of natural gas will be reasonably secure even as it becomes a major component of the nation's fuel mix. The risk stemming from fixed sources of supply of natural gas can be reduced by prudent planning. *Israel must have provision for storing standby supplies of switch fuels, primarily diesel.*

There is a case to be made for deferring construction of an Israeli LNG terminal until more is learned about other sources of supply and the scale of domestic need. A decision to immediately exploit domestic reserves and then add LNG when and if it appears there will be a future need can lead to satisfactory outcomes with respect to cost, depletion, and security of supply under many plausible sets of future conditions. Preparations for the LNG terminal may be made and approved in advance, permitting more-rapid implementation if signposts indicate that it would be expedient to do so.

Israel needs reasonable levels of standby reserve capacity at power plants and for the major levels of central storage to smooth possible jolts to the supply system. Also, *the planned inland high-pressure natural-gas pipeline should be built* to transport the volume of natural gas likely to be required, to provide some degree of redundancy in means for supply, and to provide more capacity for in-line storage.