Engineering Analysis of the Fire Miracle on Mount Carmel

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Thermodynamic Analysis of the Fire Miracle on Mount Carmel

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Abstract

The engineering analysis discussed here considers the minimum estimated energy and power that would have been required for the fire miracle on Mount Carmel in 1 Kings 18 that destroyed an altar made of stones, a sacrificial bull, and twelve containers of water poured onto the sacrifice. The purpose is not to determine precise values but rather to calculate order of magnitude estimates. The analysis shows the fire was unnaturally hot, the vast majority of the energy would have been used to destroy the stones used to make the altar, and the amount of power would have been comparable to a modern power plant. The results show the unmatched power and sovereignty of God.

Introduction

1 Kings 18 has been called "one of the most dramatic chapters in the Bible" (Olley 34). "Fire from heaven on Mount Carmel is among the most stunning and impressive miracles in the Old Testament" (Baukal, Pyrotechnics 289). The encounter on Mt. Carmel was "perhaps Elijah's central episode" according to Levine (34). Keller (91) describes this event in his own inimitable style:

> A flash of fire fell upon the evening sacrifice. The flames blazed and burned with fury. The temperatures were so intense the water was instantly turned to steam. The great joints of beef and piles of wet wood were consumed in moments. Even the twelve large boulders and the damp soil all around were oxidized and obliterated by the holocaust.

This event might be viewed as a court case where the prophets of Baal act as the prosecuting (persecuting?) attorneys trying to protect Baal's honor and sovereignty. Elijah acts as the defense attorney protecting Yahweh's honor and sovereignty. The jury in this case is the people (Tonstad

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253-66) who will have to decide which god to ultimately follow, as Elijah has called them to make a choice as to which god they should worship. This summit contest pitted a present god YHWH against an absent god Baal (Glover 451).

Altar

Elijah had to rebuild an existing but abandoned altar.[2] Israelites were not normally supposed to make sacrifices outside the Temple, but there are some possible explanations for the existence of this broken-down altar outside Jerusalem. The unusual circumstances of having a Jewish monarchy (Ahab) dedicated to serving Baal[3] may have dictated having an altar far away from the king (Slotki 133). Another possibility is this altar[4] was built before the Temple was constructed (Hammond 424). These worship sites were a fundamental element of Israelite life up until the construction of the Temple (Nakhai 21). For example, in the time of Solomon "The people were still sacrificing on the high places, because there was no house built for the name of the Lord" (1 Kings 3).

The altar may have fallen into disrepair because of the persecution of Yahweh's prophets by Jezebel (Konkel 300). Elijah rebuilt the altar himself (1 Ki. 18:30) even though he at least had one servant with him (v. 43) as well as numerous bystanders who could have helped rebuild it. This should not have been a problem since Elijah was apparently in excellent shape because he later outran Ahab's chariot to Jezreel some distance away. He did not have to build a new altar

2. It is ironic that Elijah rebuilt an altar he was planning for Yahweh to destroy with fire shortly after it was rebuilt.

3. 1 Kings 16:33 notes "Ahab did more to provoke the LORD God of Israel than all the kings of Israel who were before him."

4. There are some similarities between the description of the site on Mount Carmel and what was believed to be a cultic site that was found on Mount Ebal (Zertal, "Early Iron Age" 105-165). Large quantities of ash, coals, burnt wood and animal bones, including many cattle bones, were found at the site (111, 115). The site was elevated (105) and appeared to be designed for a relatively large crowd (157).

from scratch, but rather chose a location with an existing, albeit broken down, altar. This altar should have been a strong reminder to the Israelite spectators of what was once done at that location. Israelites sometimes had their own legitimate high places for worship but often kept Canaanite traditions alive by having illegitimate worship centers at the same location (De Vaux 288). That was likely the case on Mount Carmel. Whitney (125) called such places "the chief crucible for the conflict between the faith of Israel and the religion of Canaan." The existence of altars for both gods made this location ideal for the showdown.

Elijah rebuilt an existing altar that had either fallen into disrepair, or more likely had been torn down (1 Kings 19:10, 14). Rebuilding this altar symbolically demonstrated Elijah was reclaiming the cultic site for Yahweh (Zannoni 269). Elijah added twelve stones representative of the twelve tribes of Israel (v. 31) and reminiscent of Moses' and Joshua's erection of twelve stones at Sinai (Ex. 24:4) and in the middle of the Jordan River (Josh. 4), respectfully. The symbolism of putting twelve stones representing the twelve tribes of Israel (v. 31) would not have been missed by the spectators.[5] The twelve stones were a symbol of the unity of the people (Heger 119). The stone altar on Mount Carmel is not the only stone altar mentioned in the Old Testament.[6]

In addition to arranging the twelve stones for the altar, Elijah also made a trench around the altar which was filled with water. The trench may have been made to create a barrier to keep the heavenly fire contained (Cogan 443). While the trench could have been dug to increase the

5. This symbolism was also used in an earlier miracle when the Jordan river was parted for the Israelites to go into the Promised Land and a memorial was erected using twelve stones from the riverbed (Josh. 4:1-7).

6. Yahweh gave instructions for Moses for making an altar of uncut stone (Ex. 20:22-25); Moses gave instructions on setting up an altar of uncut stones on Mount Ebal after the Israelites crossed over the Jordan (Deut. 27:4-8); the people of Beth Shemesh offered the cows who brought back the Ark on an altar consisting of a large stone (1 Sam. 6:13-14).

amount of water to be evaporated to further heighten the miracle, it could also have been the usual way of preparing a place of sacrifice to catch the blood running from the sacrifices (Heger 80). The trench may be an indicator of the width of the flame as the heat from the fire evaporated the water.

A high place is situated on a natural or manmade elevated location (Barrick 566). First and Second Kings both warn about high places used to sacrifice to other gods.[7] However, the altar here is referred to specifically as an "altar of the LORD" (1 Ki. 18:30) which indicates this particular offering site was sanctioned by Yahweh (Van't Veer 242). The altar on Mount Carmel could have been recently used in Israel based on Elijah's later comments about the people of Israel having torn down Yahweh's altars (1 Kings 19:10) (Van't Veer 243). The altar most likely was torn down as part of Jezebel's religious persecution (Monson 79). The irony of Elijah rebuilding the altar on Mount Carmel is that no altar had been built in Israel for years, nor had any sacrifices been offered to God for many years. Another possible reason for the selection of Mount Carmel for this contest may have been the availability of an altar of Yahweh, albeit in need of repair (Patterson and Austel 146).

Heavenly Pyrotechnics

The fire used on an altar of Yahweh in the Old Testament was very special, "this fire upon the altar was sacred, possessing positive purifying and sanctifying power" (Morgenstern 6). God sent fire from heaven at the dedication of the altars at: the tabernacle in the desert (Lev. 9:22-24), David's altar built on the threshing floor of Ornan (1 Chron. 21:26), Solomon's Temple (2 Chron. 7:1), and Elijah's rebuilt altar on Mount Carmel (1 Kings 18:30-38) (Morgenstern 6-26).

7. 1 Kings 13:32-3; 14:23; 15:14; 22:43; 2 Kings 12:3; 14:4; 15:4, 35; 16:4; 17:9, 11, 29, 32; 21:3.

Fuel

Elijah instructed the prophets of Baal to place their sacrifice on an altar with wood (1 Ki. 18:23). This wood likely came from the dwarf-oaks and olive trees that are common on Mount Carmel (Cook 204). However, this wood was not the main fuel used to consume Elijah's sacrifice. Some have suggested Elijah used some trickery by pouring fuel such as naphtha, which is naturally-occurring and clear, instead of water on the sacrifice or by using flammable stones made out of bitumen, but that is unlikely (Ibid.).

Although God could have performed this miracle any way He chose, an attempt will be made here to describe the minimum aspects of the miracle using our current understanding of combustion. For the fire to have come literally from the sky, the fuel would have to have been heavier than air so that, for example, it probably would not have been natural gas or hydrogen which are both lighter than air and tend to rise rather than fall. Gaseous fires tend to be extremely buoyant and therefore do not normally burn downwardly unless there is a high momentum fuel jet oriented directed downward. Gaseous fuels such as natural gas and hydrogen tend to burn with relatively little luminosity and therefore would not have been as easily seen from a distance as other fuels. If the fuel was a gas, it would probably have been something like propane or butane which are both heavier than air, would naturally have fallen down, and would have burned with considerable luminosity to be easily seen from a long distance (Baukal, *Heat Transfer* 103). The advantage of a gaseous fuel is that it is easier to ignite and more easily mixes with air to combust compared to liquid and solid fuels.

The fuel could have been a liquid, like oil, since liquid fuels are much heavier than air and naturally fall downward. God could certainly have used other liquid fuels like gasoline and diesel that do not occur naturally, did not exist at that time, and are produced through complex

processing of crude oil. If a liquid fuel was used, it could have been "poured" from the sky onto the altar, somehow ignited, and burned in a streaming column. One of the problems when using a liquid fuel is that it must be sufficiently atomized (broken up into fine particles) to produce a stable flame so the streaming liquid fuel would also have had to have been continuously atomized as it fell to earth. If it was all atomized in the sky and then fell to earth, the vaporized liquid fuel could have become too light to fall to earth and the fire would then have been uncontrolled.

It is possible that even a solid fuel, such as bitumen,[8] could have been used because solids are also much heavier than air and naturally fall downward. However, this is less likely (on a natural basis) because solid fuels are even more difficult to ignite and burn than liquids (Ragland and Bryden 24).

Thermal spallation is a technology using flames to "drill" through rocks (Rauenzahn and Tester 381-99). These flames typically use pure oxygen, instead of air, to oxidize the fuel because the resulting flames are much hotter. Air contains mostly nitrogen (N_2) which acts as a ballast to reduce the temperature of a flame compared to using pure oxygen. For example, the maximum possible or adiabatic flame temperature (AFT) of an air-methane flame where both the air and methane are initially at ambient temperatures is approximately 1980°C (3600°F), while the AFT of an oxygen-methane flame is over 2760°C (5000°F) (Baukal, *Oxygen-Enhanced Combustion* 17). These high temperature flames are used, for example, to melt sand in the production of glass (Eleazer and Hoke 215-36). Therefore, pure oxygen may have been used to combust the fuel raining from heaven to produce a flame hot enough to consume stones. There is no natural explanation for the source of this pure oxygen, which is produced today by various air

8. Rich deposits of bitumen have been found in the region of Palestine (Forbes 27).

separation techniques (Kerry 77-87; McGuinness and Kleinberg 43-75).

The combustion process was at least efficient enough that apparently no significant smoke was produced as there is no mention of smoke in the narrative. Smoke is mentioned many times elsewhere in the Old Testament,[9] so it would likely have been mentioned if it were present on Mount Carmel. It is also possible that smoke could have been generated but was not as visible because of the time of the day since the miracle was at dusk where the darker sky could have masked any smoke. Another reason it is unlikely any significant smoke was produced is that would have reduced the visibility and therefore the impact of the fire from heaven. The lack of smoke suggests the most likely fuel would have been a gas, which normally produces less smoke than liquid or solid fuels (Baukal, *Industrial Combustion Pollution* 529).

Fire

Elijah arranged the wood and cut the ox into pieces and laid them on the wood (1 Ki. 18:33), just as the priests had been commanded to do by God (Lev. 1:7-8). Proverbs 26:20 emphasizes the need for fuel to keep a fire going, "For lack of wood the fire goes out." Wood was the source of fuel used for an altar fire (Lev. 3:5).

The combination of fire and a sacrifice is significant (Ryken 507):

> Elijah prayed for fire because before the people could receive any other blessing from God, they needed to receive atonement for their sins. They needed to get right with God before they could get any rain from God. Remember that the reason there had been no rain in the land was that the people had sinned against God. Drought was God's particular punishment for idolatry: "Take care lest your heart be deceived, and you turn aside and serve other gods and worship them; then the anger of the LORD will be kindled against you, and he will shut up the heavens, so that there will be no rain, and the land will yield no fruit, and you will perish quickly off the good land that the LORD is giving you" (Deut. 11:16-17).

Many commentators (e.g., Allen 199; Ap-Thomas 153; Auld 120; Bronner 63; Monson 80;

9. E.g., Exod. 19:18, 20:18; Lev. 16:13; Josh. 8:20-21; Judg. 20:38-40; Isaiah 9:18.

Matheney and Honeycutt 211; Van't Veer 281; Walsh 253; Wood 91) have suggested lightning, instead of fire, was used to consume the offering. However, this misses an important part of the miracle which is the simulation of an evening sacrifice on a grand scale. Lightning was not used for a normal evening sacrifice – fire was, which is why real fire is the more likely source of energy to consume the sacrifice on Mount Carmel, simulating an evening sacrifice on steroids.

Besides fire and lightning, a volcanic eruption has been offered as a possible source of the "fire" from heaven, although this is summarily dismissed as Mt. Carmel is a limestone spur which makes volcanic activity highly unlikely (Ap-Thomas 150-1; Skipwith 690).

Energy Analysis

High intensity flames consumed the water-soaked sacrifice, evaporated a large quantity of water around the altar, and even consumed the stones used to make the altar. The minimum amount of energy needed for this miracle can be estimated. There are several components of the heat load: the stones used to make the altar, the water poured on the altar that soaked the bull and altar, and the bull sacrificed on the altar. Each of these is considered next.

Altar

The exact shape of the altar is unknown, although altars built during this period in Israel's history were probably simple and low in stature (Heger 170). Two general types of altars have been discovered in Palestine dating back to the Old Testament: Type I which is taller and more circular and Type II which is shorter and more oblong (Vaughn 40-55). Some of the former have been as large as 14 m (46 ft) in diameter and some of the latter as long as 18 m (59 ft). An example is the altar found on Mt. Ebal which was an earth and stone structure approximately 7 m

x 9 m x 3 m high (23 ft x 30 ft and10 ft high) (Zertal, "Has Joshua's altar been found" 40).[10] An Old Testament altar had to be substantial in size to hold a sacrifice as large as an ox and the wood necessary to burn a large animal (Gadegaard 35-45).

While it is impossible to know how big Elijah was, a reasonable estimate can be made to determine how large the stones used to build the altar may have been. The average height and weight of an Israelite man from this time period was approximately 5'0" (152 cm) (Matthews 3) and 65 kg (143 lb), respectively. It is assumed Elijah was of average size as the Bible often notes when a person was exceptionally large such as king Saul (1 Sam. 10:21-23) and Goliath (1 Sam. 17:4). It is also assumed Elijah was of average strength as the Bible also notes when a person is exceptionally strong such as Samson (Judges 16:5). Elijah was likely to have been in excellent physical condition as he outran king Ahab who was in a chariot from Mount Carmel to Jezreel (1 Kings 18:44-46) which is roughly a distance of 16 km (10 miles). Strength Level (www.strengthlevel.com) has sampled thousands of people to determine standards for weightlifting in five categories ranging from beginner to elite in a variety of lift types. The one-repetition maximum performance for a front squat for a 65 kg (143 lb) male ranges from 45 to 140 kg (99 to 309 lb). More weight can be lifted for a normal squat over the shoulder and even more for a deadlift. Because of the bulky nature of a large stone, the weight for a front squat for a novice will be assumed here as a minimum instead of the larger weights for a normal squat and deadlift. The front squat lift weight for a novice weightlifter is 63 kg (139 lb) will be used here. While Elijah was likely in excellent condition and there is some evidence to suggest people were generally in better condition in ancient times due to diet and more physical lifestyles, he may

10. This is comparable in size to Solomon's Temple Altar and Ezekiel's Visionary Temple Altar, although considerably bigger than the Tabernacle Altar.

have had to carry the stones some distance and he carried twelve of them which would reduce the amount of weight for each stone he could carry compared to a single lift.

Elijah repaired an altar of the LORD using twelve stones (1 Ki. 18:30-32). These stones most likely came from Mt. Carmel, i.e., they were probably not brought up to the mountain by Elijah or his assistant. The stones used by Elijah were likely made of limestone because Mount Carmel is in a limestone ridge (Hallner and Rosenau 61-80). The stones were likely of a size that could be handled by Elijah himself. Although Elijah had a servant with him, Elijah carried the twelve stones to make the altar (1 Kings 18:31-32). In Joshua 4:5, Joshua told each representative of the twelve tribes to take up a stone on his shoulder which indicates the size and weight of each stone could be handled by a single man. It is likely that was the case for the stones used by Elijah.

The density of typical limestone made primarily of calcite ($CaCO_3$) is 2.72 g/cm^3 (170 lb/ft^3) (Oates 18). Then, a 63 kg (139 lb) stone would have a volume of 0.023 m^3 (0.081 ft^3). If the stones were spherical, they would have a diameter of 35 cm (14 in.) which is not too bulky to carry. Then the total mass of twelve stones weighing 63 kg (139 lb) each is 756 kg (1670 lb).

The total cross-sectional area of these spherical stones with no gaps between them would be 1.2 m^2 (13 ft^2). It the stones were aligned instead of staggered with their edges touching to make a single layer, then the cross-sectional area would be 1.5 m^2 (16 ft^2). With mortar between the stones, the cross-sectional area would be at least 2 m^2 (22 ft^2). That would be barely enough to hold a bull by itself. The stones were probably not perfectly spherical and were probably somewhat flatter which means they could have been laid in such a way to cover even a larger total area than if they were spherical. It will be assumed here that Elijah's stones provided a second layer over an existing base layer remaining from the broken-down altar. Given the size of the altar found on Mt. Ebal, it is likely the altar on Mt. Carmel was much larger than assumed

here which provides a minimum size.

Then for two layers of limestone rock as assumed here, the total mass would be approximately 1,500 kg (3300 lb). The average specific heat of calcite (Oates 20) between 0 and 800°C (32 and 1500°F) is 1.1 kJ/kg-K (0.26 Btu/lb-°F). Calcite dissociates into quicklime (CaO) and carbon dioxide (CO_2) at 900°C (1700°F). The sensible energy to heat the limestone from 20 to 900°C (70 and 1700°F) then is approximately 1.5×10^6 kJ (1.4×10^6 Btu). The heat of dissociation for limestone (Oates 21-2) at 900°C (1700°F) is 1,686 kJ/kg (725 Btu/lb). Then the energy needed to dissociate the limestone into quicklime is approximately 2.5×10^6 kJ (2.4×10^6 Btu). The thermal decomposition of calcite can be written as:

$$\underset{100g}{CaCO_3} + \text{heat} \leftrightarrow \underset{56g}{CaO} + \underset{44g}{CO_2} \qquad (1)$$

After the calcite is dissociated, there remains 1500(56/100) = 840 kg (1,850 lb) of lime. The melting point of CaO is 2580°C (4680°F) and the mean specific heat is 0.762 kJ/kg-K (0.182 Btu/lb-°F) (Oates 118). The sensible energy to heat the lime from 900°C (1700°F) to the melting temperature of 2580°C (4680°F) is 1.1×10^6 kJ (1.0×10^6 Btu). The heat of fusion for lime (Kelley 134) is 915 kJ/kg (393 Btu/lb). The amount of energy needed to melt the lime would be 7.7×10^5 kJ (7.3×10^5 Btu). Further energy would be needed to heat the liquid lime to its boiling temperature and then to vaporize the lime. The specific heat of liquid CaO (Chase 730) is 1.12 kJ/kg-K (0.268 Btu/lb-°F) so the sensible energy to heat the liquid lime to its vaporization point would be 2.5×10^5 kJ (2.4×10^5 Btu). The heat of vaporization of liquid CaO (Babeliowsky 1157) is 1.04×10^4 kJ/kg (0.99×10^4 Btu) so the energy to vaporize the liquid lime is 8.7×10^6 kJ (8.2×10^6 Btu). Then, the total energy needed to vaporize the stones is 1.5×10^7 kJ (1.4×10^7 Btu).

Water-Soaked Sacrifice

Four pots of water were poured on the altar three times. While this certainly heightened the miracle, it was also likely a direct affront to Baal who was supposed to be the god that provides rain which had been lacking in the land for over three years (Baukal, Hydrotechnics 67). It is not known exactly how much water was used to saturate the sacrifice. Typical larger Israelite pots held approximately 32 liters (8.5 gal) while smaller pots held about half that amount (King and Stager 139-46). The pots used in this narrative were more likely the smaller pots (Monson 80). Therefore, the twelve pots of water poured on the offering may have totaled from 192 to 384 liters (51 to 101 gal). Using the smaller volume, this equates to approximately a total of 191 kg (421 lb) of water. Using 4.2 kJ/kg-K (1.0 Btu/lb-°F) as the specific heat of water (Cengel and Boles 902) and assuming the water was heated from 20 to 100°C (68 to 212°F), this equates to a sensible energy requirement of 6.4×10^4 kJ (6.1×10^4 Btu). Using a heat of vaporization of 2257 kJ/kg (970 Btu/lb) for water (Ibid.), the energy required to vaporize the water would be 4.3×10^5 kJ (4.1×10^5 Btu).

Bull

Elijah's animal sacrifice was a bull. Domesticated cattle in the Bible were likely of the brachyceros type (Jonas 94). The two most common breeds in Palestine today are the Arabian and the Golan which have average weights of approximately 225 and 263 kg (496 and 580 lb), respectively based on a sample of 78 cows (Jonas 96).[11] It is impossible to know how large the bull was that Elijah sacrificed, especially since some sacrifices were of animals approximately

11. The ages and genders of the 78 cows were not given so it is unknown how many were bulls that may have been one year old.

one year old (e.g., Lev. 9:3) (Borowski 215).[12] For the sake of this analysis since it is unknown how big the bull was that Elijah sacrificed, it will be assumed it was the smaller bull and weighed 225 kg (496 lb).

It might be assumed the wood piled on the altar would have provided enough energy to consume the bull without any additional energy such as a fire from heaven. However, that wood would not have naturally burned because it was soaked with the water poured over the sacrifice. The fire from heaven would likely have consumed the bull before the wood because it was on top of the wood shielding it initially from the heavenly fire. The bull would have likely been incinerated before all of the water evaporated from the wood. Therefore, for the purposes here it will be assumed that energy was needed to incinerate the bull and to evaporate the water from the wood, but not to burn the wood. Once the wood was dried, it would have released heat when it burned. Since the bull would already have been incinerated and the water evaporated, the energy from the wood would not have been enough to consume the stones which normally held the wood for a normal sacrifice. Therefore, the energy from the burning wood will be assumed to have a negligible effect in this analysis.

Specific data on the energy required to burn a bull carcass could not be found. According to the U.S. Department of Agriculture, the following materials are recommended for the open-air burning of an unspecified size adult bovine carcass: 3 bales of straw or hay, 3 pieces of untreated heavy lumber, 50 lb (23 kg) of kindling wood, 100 lb (45 kg) of coal pieces 6-8 in. (15-20 cm) in diameter, and 1 gallon (3.8 liters) of liquid fuel (not gasoline) (U.S. Dept. of Agriculture 14-57). As can be seen, this is not very specific as the exact mass and type of each fuel are not provided.

12. Borowski noted that one year old cows were typically referred to as calves and older cows as bulls so it can be assumed Elijah's sacrifice was an adult male cow.

An alternative approach is to assume the bull was approximately 60% water by mass. This fraction was determined from data collected from the carcasses of 58 Holstein and Angus bulls (Fortin et al 604-14). Lacking further information, it will be assumed the rest of the bull, particularly the fat which contains significant heating content, does not require any additional energy to burn. This estimate is likely the least amount of energy required to incinerate the bull. Using the same approach as for the water poured on the sacrifice, 4.6×10^4 and 3.1×10^5 kJ (4.4×10^4 and 2.9×10^5 Btu) would have been required to heat the water in the bull up to the vaporization temperature and to vaporize the water, respectively. The total estimated energy requirement then is 3.6×10^5 kJ (3.4×10^5 Btu).

Another approach is to consider the energy needed to incinerate a cow in a modern carcass incinerator. These combustors are well-insulated and nearly adiabatic chambers, so the energy requirements should be close to the energy needed just to incinerate a carcass. Fuel requirements were taken from the manufacturers' data sheets to determine the energy required to incinerate a 225 kg (496 lb) bull. An Addfield (www.adfield.co.uk) model TB Animal Carcass Waste Incinerator, Inciner8 (www.inciner8.com) model I8-250, and The Incinerator Company Ltd model TICA 900 Animal Carcass Waste Incinerator would require approximately 1.1×10^6, 1.4×10^6, and 9.9×10^5 kJ (1.0×10^6, 1.3×10^6, and 9.4×10^5 Btu), respectively of energy to incinerate a 225 kg (496 lb) bull. These are all relatively close to each other. The average of these three is 1.2×10^6 kJ (1.1×10^6 Btu).

Since the incinerators are not 100% thermally efficient, the actual energy just to incinerate a bull would be lower than 1.2×10^6 kJ (1.1×10^6 Btu). The energy estimated assuming the bull was 60% water of 3.1×10^5 kJ (2.9×10^5 Btu) likely underestimates the total energy required. A closer estimate is likely somewhere between these two values. For the purposes here, an average

of these will be used: 7.6 x 10^5 kJ (7.2 x 10^5 Btu).

Discussion

The minimum estimated energy requirements calculated above are summarized here:

Energy to:	Energy (kJ)	Fraction (%)
Destroy the stones:	1.5 x 10^7 kJ	92
Evaporate the water poured on the sacrifice:	5.0 x 10^5 kJ	3
Destroy the bull:	7.0 x 10^5 kJ	5
Total	1.6 x 10^7 kJ	100

As can be seen, the vast majority of the energy is needed to destroy the stones, with much less needed for the water and the bull.

The energy distribution to destroy the stones is as follows:

Energy to:	Energy (kJ)	Fraction (%)
Heat limestone to dissociation:	1.5 x 10^6	10
Dissociate limestone into lime + CO_2:	2.5 x 10^6	17
Heat solid lime to its melting temperature:	1.1 x 10^6	7
Melt lime:	7.7 x 10^5	5
Heat liquid lime to its vaporization temperature:	2.5 x 10^5	2
Vaporize liquid lime:	8.7 x 10^6	59
Total	1.5 x 10^7	100

Most of the energy to destroy the stones is used to vaporize the liquid lime.

This estimate is the bare minimum assuming no heat losses. In fact, the heat losses would have been very high because there was no insulated chamber surrounding the altar to hold in the heat. Given the high heat flux and relatively low ambient temperature compared to the flame, the radiant losses to the environment would have been very high. For the sake of argument, assume at least double the amount of energy would have been needed to account for the heat loss to the environment. The losses were likely higher than that but we're attempting to estimate the minimum energy needed so a conservative estimate is used here.

The next consideration is how much power would be required which depends on how long it took for this miracle to occur. Since that is not known, a range of times will be considered

with as short as 1 second and as long as 1 minute. Figure 1 shows the minimum estimated power that would be required depending on how long the fire impinged on the sacrifice, assuming the rate was steady.

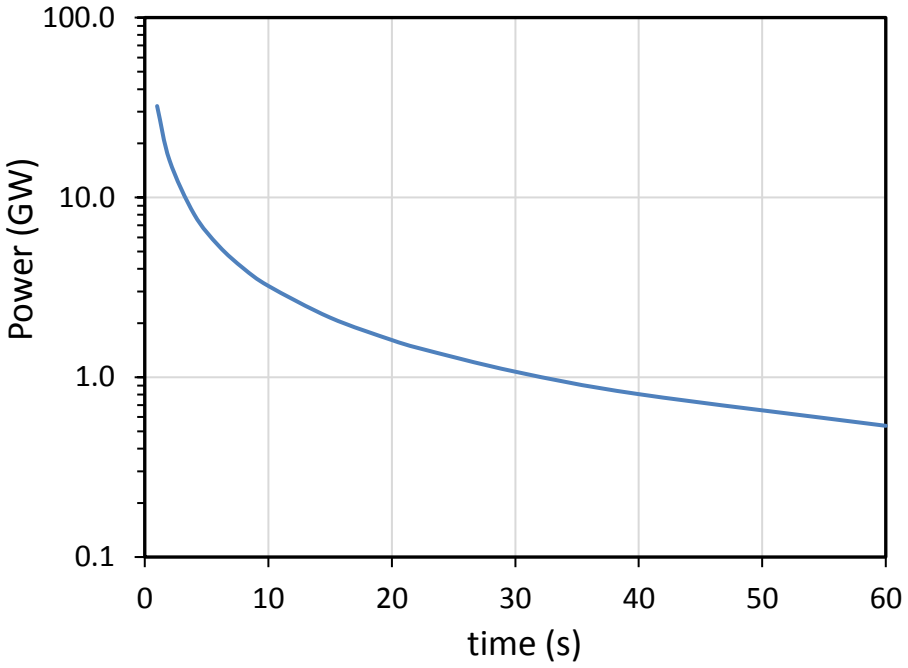

Figure 1 Power (GW) required as a function of time (s).

A typical power plant is on the order of approximately 500 MW. Based on the above analysis, that would have been the minimum amount of power used even if the flame impingement lasted for as long as a minute.

According to Edersheim (1 Kings 18), "That day Carmel witnessed one of the grandest scenes in the history of Israel." It is tempting to give Elijah too much credit for the victory on Mount Carmel. To put this narrative in proper context, Pritchard (113-4, italics his) wrote, "*This is the story about God*. It is not about Elijah. He's just the instrument through whom God works an incredible miracle."

God's use of fire in this miracle was particularly significant, "The veneration of fire by most

nations is not surprising if we consider that there is probably no agency more powerful for good or ill in the universe, than fire" (Bronner 54). The fire sent from heaven to the altar on Mount Horeb "provides stunning confirmation that YHWH is G-d" (Sweeney 209). On the uniqueness of this fire, Wood (92) wrote, "Fire that consumes stones and dirt cannot be kindled by human hand." Ryken (479) described it as no mere fire but a "mighty conflagration."

Conclusions

The purpose of this exercise was to determine where most of the energy would have been needed for the fire miracle on Mount Carmel and to get an order of magnitude estimate of how much power this would have required. The calculations attempted to estimate the minimum requirements, so the actual amount of energy used on Mount Carmel was likely much larger than estimated here. Based on the calculations, it appears most of the energy would have gone to destroy the stones and the amount of power required would have been comparable to today's power plants. Archaeologists have found altars in Palestine dating back to the Old Testament that are much larger than the size used here, where the energy needed to vaporize them would have been much larger than calculated here. The flame temperature needed to vaporize the altar stones would have been higher than could be produced by normal air-fuel flames and could not have been produced naturally.

This would have been a spectacular and awe-inspiring event that would likely not have been forgotten by any who were present that day. The onlookers must have been far enough away from the heavenly fire that none were injured but undoubtedly they felt the heat from the flames. Add to that the fire was displayed against the night sky and it would likely have rivaled the best fireworks displays today.

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