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Project Summary

Feasibility of Producing Commodities and Electricity for Space Shuttle Operations at Vandenberg Air Force Base

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The report gives results of an analysis of the technical and economic feasibility of the on-site production of commodities (liquid propellants and gases) and electricity to support space shuttle launch activities at Vandenberg Air Force Base (VAFB).

Both commercial and developing systems were considered. Systems to supply electricity were considered to meet continuous electricity demands only, critical launch demands only, or both continuous and critical launch demands. In addition to systems to supply commodities only, several systems to produce both commodities and electricity were considered. All systems were evaluated for technical risk, conversion efficiency, environmental impacts, reliability, and economics.

A major finding is that over the near term (1992 to 2013), VAFB cannot produce electricity at a price competitive with purchased electricity. Also, unless hydrogen markets on the West Coast fundamentally change, there is no incentive to produce liquid hydrogen (the commodity of primary interest) on-site at VAFB. These and other findings were used to recommend possible follow-up actions to the USAF.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The technical and economic feasibility of the on-site production of commodities (liquid propellants and gases) and electricity to support space shuttle launch activities at Vandenberg Air Force Base (VAFB) was analyzed. This is a summary of the principal conclusions and recommendations of the completed feasibility study.

The two-fold purpose of this study was: (1) because of the potential to reduce the costs and improve the reliability of supply of electrical power and commodities, the USAF was interested in *evaluating alternatives for the on-site production of commodities and electrical power at its Western shuttle launch site at VAFB;* and (2) because the existing backup power supply at VAFB is unable to support shuttle launch operations if the primary power supply fails, and can support only the shutdown of launch operations, the Air Force was interested in *determining the most cost effective ways of providing a reliable backup power supply that could allow the completion of launch operations.* The backup power systems could be used alone or as part of systems used for the continuous production of commodities and electricity.

The feasibility study covered the period from 1992 (the year presumed for the start-up of on-site plants) to 2013 (the presumed end of the useful life of on-site plants). Both commercial and developmental concepts were considered. The energy and feedstock resources considered for use in on-site plants were: fuel oils, natural gas, coal, wind, water, and solar. The products from these on-site plants included electrical power and the following commodities: liquid hydrogen, liquid oxygen, and liquid and gaseous nitrogen. A total of 19 technologies were considered for energy and feedstock conversion, generation, and storage, including: external combustion (boilers), steam turbines, gas turbines, combined cycle turbines, internal combustion (diesels), gasification (coal), partial oxidation (oil), steam reforming (natural gas), fuel cells, electrolysis, air separation, solar central receivers, solar photovoltaics, pumped hydro storage, and wind turbines.

The preceding concepts were considered in the following applications: 1) continuous production of electricity (with and without capability to supply reliable backup power for completing shuttle launches), 2) critical launch backup power, 3) commodities production, and 4) production of both commodities and electricity. After evaluating the production options, the best systems were identified by considering technical risk, conversion efficienc;y, environmental impacts, reliability, and economics.

Conclusions

The four major conclusions of this study are:

1) Continuous electricity production

- *Except as noted below, VAFB cannot produce its own electricity at a price competitive with purchased electricity. Fossil fuel based systems for producing electricity are not economically viable due to their relatively small size and consequently their low conversion efficiencies. Most non-fuel based systems, such as solar photovoltaics, are not economically viable because of their high capital cost and relatively low operating factor.* The economic viability of electricity production at VAFB is also adversely affected by the relatively low value of electricity and the relatively high cost of fuels at VAFB.
- *Electric power from small wind turbines located on well-exposed ridgecrests in southern VAFB appears to be economically viable.* Additional study is required to verify the available wind resource at VAFB, to provide a more detailed design and cost analysis, and to determine the long-term reliability, operability, and performance characteristics of a wind turbine system.

2) Critical launch demand power

- *Pumped hydro storage systems are the lowest cost options for supplying critical launch demand power at the shuttle launch complex,* unless more than about 24 hours of pumped hydro storage capacity is needed. (Twenty-four hours of storage is about twice the 11 hour duration of critical launch demands.) These storage systems could also be used daily for VAFB power load management. Gas turbine and diesel systems, the next best systems to meet critical launch demands, will be more costly than pumped hydro systems.
- Except for the possible use of pumped hydro storage in power load management, *none of the systems considered to supply critical launch demand power should be considered for continuous service.* Continuous service could reduce system reliability, and the high fuel, operating and maintenance costs make continuous service uneconomic.

3) Commodities production

- Because the USAF currently purchases liquid hydrogen on the West Coast at prices substantially below commercial market prices (~50% discount),*there is currently no incentive to produce liquid hydrogen on-site at VAFB.* This situation is expected to continue as long as excess liquid hydrogen production capacity exists on the West Coast. If the excess liquid hydrogen production capacity disappears, the USAF will probably have to pay commercial prices for liquid hydrogen. At that time, on-site production of liquid hydrogen (by the steam reforming of natural gas or the electrolysis of water) becomes economically attractive. It is not possible to predict when, if ever, the USAF would begin to pay commercial prices for liquid hydrogen.
- *The on-site production of liquid oxygen, liquid nitrogen, and gaseous nitrogen by air separation is somewhat less expensive than the continued purchase of these commodities.*

4) Commodities and electricity production

- The use of a polygeneration concept, such as the coal gasification/combined cycle turbine concept being considered at the Kennedy Space Center (to produce electrical power, liquid hydrogen, and gaseous nitrogen), is uneconomic at VAFB. At VAFB, polygeneration capacities are small, electricity and liquid hydrogen prices or values are low, coal costs are relatively high, and relatively more electricity (less valuable than liquid hydrogen) would be produced.
- Novel wind turbine combinations (with electrolysis or air separation) are potentially attractive pending verification of the wind resource at VAFB.

Overall system evaluation and ranking summaries shown in Tables 1 through 3 are highlighted below.

- Despite the differences in basic unit reliabilities shown in Table 1 through 3, by adding spare units, all systems except wind turbines and solar systems can be designed to meet the reliability constraints that would allow the on-time completion of shuttle launches.
- Except for the steam reforming of natural gas to produce liquid hydrogen, all fossil fuel based systems have negative ratings in at least two of the four major areas of evaluation (technical, economic, environmental, and reliability). The most common negative ratings for fossil fuel based systems are in economic and environmental areas. Systems featuring the gasification of coal have negative ratings in all four areas of evaluation.
- All non-fuel based systems (wind turbines, solar photovoltaics, solar central receivers, pumped hydro storage, air separation, electrolysis, and combinations of wind turbines with air separation or electrolysis) have positive or neutral ratings in at least three of the four areas of evaluation. Air separation systems have positive ratings in all four areas. Under current trends, steam reforming and electrolysis to produce liquid hydrogen are negatively rated in the economic area. But, if the USAF had to pay commercial prices for liquid hydrogen, steam reforming and electrolysis would be positively rated in the economic area as well. Solar photovoltaic systems have a negative rating in the economic area, based on the current best estimates of costs for mature solar photovoltaic systems in 1992. Since much on-going research is aimed at reducing the costs of photovoltaic cells and systems, the economic rating could eventually change to positive.

Table 1. Overall System Ratings

System	Areas of Evaluation: Technical[a]	Economic[b]	Environmental[c]	Reliability[d]
Electricity Production				
Boiler/Steam Turbine				
Natural gas	+	—	—	0
No. 2 fuel oil	+	—	—	0
No. 6 fuel oil	+	—	—	0
Stoker coal	+	—	—	0
AFBC	+	—	—	0
Gas Turbine				
Natural gas	+	—	—	0
No. 2 fuel oil	+	—	—	0
Combined Cycle Turbine				
Natural gas	+	—	—	0
No. 2 fuel oil	+	—	—	0
No. 6 fuel oil (via partial oxidation)	0	—	—	—
Coal (via gasification)	—	—	—	—
Diesels	+	—	—	+
Fuel Cells				
Natural gas (via steam reforming)	—	—	+	0
No. 6 fuel oil (via partial oxidation)	—	—	—	—
Coal (via gasification)	—	—	—	—
Wind Turbines	+	+	+	0
Solar Central Receiver	0	—	+	+
Solar Photovoltaics	+	—	+	+
Pumped Hydro	+	—	+	+
Commodities Production				
Steam Reforming	+	-/+[e]	+	+
Oil Partial Oxidation	+	—	—	0
Coal Gasification	—	—	—	—
Air Separation	+	+	+	+
Electrolysis	+	-/+[e]	+	+
Coal Gasification/Air Separation	—	—	—	—
Commodities and Electricity Production				
Wind Turbines/Electrolysis	0	+	+	0/+[f]
Wind Turbines/Air Separation	0	+	+	0/+[f]
Coal Gasification/Combined Cycle Turbine	—	—	—	—

[a] "+" denotes well developed, widely applied systems in all areas; "0" denotes systems whose components are well developed but commercial applications are few or do not exist; "—" denotes systems with one or more components still in demonstration.
[b] "+" denotes positive net present value (NPV); "—" denotes negative NPV.
[c] "+" denotes inherently clean system or system with minor emissions; "—" denotes system which generates hazardous wastes and/or requires air emission offsets.
[d] "+" denotes high single-unit reliability (~95%); "0" denotes moderate single-unit reliability (~90%); "—" denotes low single-unit reliability (~85%).
[e] "-/+": "—" under government LH_2 price trends, "+" under commercial LH_2 price trends.
[f] "0/+" for wind turbines, "+" for electrolysis or air separation.

Recommendations

The major project recommendations are in the areas of: 1) continuous electricity production, 2) critical launch demand power, 3) commodities production, and 4) commodities and electricity production.

1) Continuous electricity production
- In the near term, continue to rely on power purchased from the utility grid.
- Perform more detailed evaluation of wind turbine systems. Verify wind resource at locations on well-exposed ridgecrests in southern VAFB. Perform more detailed design and economic analysis. Purchase test wind turbines of ~200 kW (possible cost sharing with vendor) and perform testing to determine reliability, operability, and performance characteristics. Investigate potential for interferences with communications. Investigate combination with pumped hydro storage to meet critical launch demands and to smooth out production variations.
- Monitor future developments in solar photovoltaics, particularly with respect to capital investment costs.
- Consider in additional preliminary cost estimates coal systems larger than 50 MW; these systems have overall conversion efficiencies much greater than the small systems considered in this study. Excess power can be exported to the utility grid.

2) Critical launch demand power
- Perform more detailed evaluation of pumped hydro storage with respect to site-specific construction design features at VAFB. Perform more detailed design and economic analysis. Define power duration requirements (12 vs. 24 hours or more). Perform more detailed comparative analysis of pumped hydro, diesel, and gas turbines. Also, further examine existing and alternate grid power supply reliability data for time between failures and time of repairs.

3) Commodities production
- Perform more detailed and cost studies of air separation (for production of liquid oxygen, liquid nitrogen, and gaseous nitrogen). Although it is marginally feasible to produce these commodities on-site, public health and safety concerns over transportation of

cryogenics could provide an additional incentive for on-site production.
- In the near term, continue to purchase liquid hydrogen from commercial suppliers.
- Monitor future trends in commercial and government liquid hydrogen prices to anticipate escalation of liquid hydrogen prices to commercial price levels.

4) Commodities and electricity production
- after more detailed investigation of wind turbine systems (as discussed above), perform detailed analysis of wind turbine systems in combination with electrolysis or air separation.

Table 2. *Most Attractive Systems for Continuous Production of Electricity and/or Commodities*[a]

	Areas of Evaluation			
System	*Technical*[b]	*Economic*[c]	*Environmental*[d]	*Reliability*[e]
Electricity Production				
Wind Turbines	+	+	+	o
Solar Photovoltaics	+	—	+	+
Commodities Production				
Steam Reforming	+	-/+[f]	+	+
Air Separation	+	+	+	+
Electrolysis	+	-/+[f]	+	+
Commodities and Electricity Production				
Wind Turbines/Electrolysis	0	+	+	0/+[g]
Wind Turbines/Air Separation	0	+	+	0/+[g]

[a]*Systems shown here are those systems from Table 1 which have at most only one negative or zero rating in the four areas of evaluation.*
[b]*"+" denotes well developed, widely applied systems in all areas; "0" denotes systems whose components are well developed but commercial applications are few or do not exist.*
[c]*"+" denotes positive net present value (NPV); "—" denotes negative NPV.*
[d]*"+" denotes inherently clean system or system with minor emissions.*
[e]*"+" denotes high single-unit reliability (~95%); "0" denotes moderate single-unit reliability (~90%).*
[f]*"-" under government LH_2 price trends, "+" under commercial LH_2 price trends.*
[g]*"0/+":"0" for wind turbines, "+"* for electrolysis or air separation.

Table 3. *Most Attractive Systems for Supplying Critical Launch Power Demand*

	Areas of Evaluation[a]			
System	*Technical*[b]	*Economic*[c]	*Environmental*[d]	*Reliability*[e]
Gas Turbine				
Natural Gas	+	0	—	0
No. 2 fuel oil	+	0	—	0
Diesel Engines	+	0	—	+
Pumped Hydro	+	+	+	0

[a]*Systems shown here have lower capital costs than alternative systems such as gas-fired boiler/turbines. Positive ratings obviously indicate positive factors, while zero ratings indicate neutral factors, and negative ratings indicate negative factors.*
[b]*"+" denotes well developed, widely applied systems in all areas.*
[c]*For systems supplying critical launch power demands only, the most important economic parameter is the total capital investment; because of their short hours of operation, operational costs are of lesser importance. The relative ranking of these systems varies with the set of design bases. The gas turbine systems would be the least expensive of the four options if: 1) pumped hydro alternatives were required to have capacities greater than 24 to 36 hours, and 2) diesel engine alternatives required multiple units to achieve the 95% reliability criterion. Based on a preliminary analysis, new diesel engines may be more reliable than gas turbines and thus could meet the 95% reliability criterion with single units. But if multiple diesel units were required, equivalent gas turbine systems would be less expensive.*
[d]*"+" denotes inherently clean system or system with minor emissions. "—" denotes system which generates hazardous wastes and/or requires air emission offsets.*
[e]*"+" denotes high single-unit reliability (~95%). "0" denotes moderate single-unit reliability (~90%).*

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The complete report, entitled "Feasibility of Producing Commodities and Electricity for Space Shuttle Operations at Vandenberg Air Force Base," (Order No. PB 85-137 099; Cost: $23.50, subject to change) will be available only from:
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