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May 16, 1983

Commissioner Charles R. Imbrecht
Chairman, California Energy Commission
1516 Ninth Street
Sacramento, CA. 95814

Subject: Seeking More Prudent Alternatives

Dear Commissioner Imbrecht:

Congratulations on your appointment to this important Commission in our State. Just as energy, the ultimate currency, has hurt our economy and wellbeing when it became scarce and precious, your guidance of the Commission can usher in an economic Golden Era of Energy Decency....Affordable, Abundant and Amicable in the Environment. Solar-photovoltaics is a prime candidate for such strategic impact in our State. Electricity, the most convenient, transportable, clean form of energy should heat and light our homes, drive our rail-truck-auto transportation, power our industries, pump our irrigation and desalinate our seawater. Pivotal to the realization of such a Golden Era are the directions taken by you in turning our vast, untapped, renewable resources to electric power.

As the Biennial Report IV succinctly notes, tax incentives, fuel cost pass-throughs and large returns on large investments push our investor owned utilities toward less affordable power. The high technology challanges of "too cheap to meter" nuclear are now marred by the engineering, construction and operational gaffes now sinking the nuclear promise. The imminent bond default in WPPSS's five NUPs now become two will hang as a dark cloud over the economy of that State for a generation. Thank heavens the past guidance in California limited the impacts of a similar Sword of Damocles over our economy. Now the Supreme Court has upheld the State's moratorium on nuclear but more importantly has affirmed the State's right "to determine— as a matter of economics — whether a nuclear plant vis-a-vis a fossil fuel plant should be built". Indeed, this examination for more prudent alternatives is built into the Administrative Code on all siting matters comming before the Commission. Language, now deleted from the Nuclear Waste Policy Act, would have lifted this right of prudency determination from the States......and will be attempted again (see AHC Filing on 82-DSA-1, 4/29/83). Nuclear proponents have lambasted dirty coal periodically as needed to further their cause and now again quietly support expensive acid-rain pollution controls to hopefully push the cost of a coal plant back above that of a nuclear plant. The cost of plant and the the mark-up on the expensive fuels for both nuclar and coal afford the highest prudent returns for the investor owned utilities.......and a continued escalation of electric costs to the ratepayer. The necessity to examine all siting cases for more prudent alternatives my be the Commission's best weapon to substitute alternative generation technologies that may be shown to be more prudent.....prudent for the ratepayers.

I have conducted a long and sometimes bitter campaign, as a private individual, to try to ensure that this more prudent alternative doctrine in the Administrative Code be exercised for the people. In 1977, near the start of the Commission, I prepared S.E.E.D.-'77, an extensive privately published analysis and conceptual plan — schedules, economics, procurement and engineering design — for a Solar Voltaic Generation system (SVG) based on the then commercially available photovoltaic cells, that could provide as much electrical generation as then consumed by the entire Nation on a land area that would fit into a 75 mile by 75 mile patch of Eastern San Bernardino County. I offered and was accepted and scheduled to travel to Sacramento at personal expense to brief the plan to the Commission. Your people asked for advance copies. Upon receipt it was found contrary to the think-small, do-it-yourself, Friends of the Earth persuasions then rampant in the Brown administration of the Commission. The briefing was summarily cancelled by the C.E.C. with the offer that any time I was in Saramento on alternate Wednesdays I could have five minutes in the public sector. I assured your Mat Ginosar that the concept had been thoroughly reviewed and confirmed by JPL scientists, thus worthy of Commission consideration. His put-down was, "have somebody in charge at JPL write a letter to Ginosar so confirming". It might then be worth Ginosar's reading. It became clear to me that it was going to take much effort to get the Commission to even hear the case for a possibly more prudent alterternative to conventional generation schemes. And to this day the Commission won't listen to or discuss the more prudent alternative evaluation criterion.

The opportunity to try the more prudent alternative idea in your court came when SCE filed an NOI for Cal-Coal. At considerable personal expense I filed for intervention and pursued an SVG Addendum to 79-NOI-3 as an alternative if found more prudent. Our Position Paper that got only perfuctory and misleading Commission Staff response showed that a 4000 MW SVG design could provide the same annual kilowatthours as that proposed in the 1500 MW Cal-Coal at a lower busbar cost and cost to the ratepayers. At the same time Laura and I bought stock in SCE and entered Shareholder Proposals in the 1980 and 1981 proxy statements and annual meetings, pressing the same alternative study and approach as used by us in the NOI intervention. Despite Board opposition we netted 6% of the shares voted each time. Despite or intervention falling apart in a ruhbarb of no attention to our more prudent alternatives issue, to their eternal credit the Commission did condition the AFC on 1-2 MW of SVG on-line by '85, 50-100 MW by '88 and 500 by '93. This was a large demonstration step forward. SCE got their first megawatt of SVG on line at Hesperia last January, two years ahead of schedule. I don't expect that they will ever be in for the Cal-Coal AFC. I will again intervene, now armed with the fact that SVG at long last is a "preferred", "Priority III" technology in the Biennial Report IV. Yet it is still a question whether the Commission recognizes and is willing to apply the more prudent alternative criterion.

Hampered by the Commission's lack of acceptance in B-R II of the SVG alternative, even though we gathered much commercial data for 79-NOI-3, we fought to ensure its consideration in B-R III. The announced generic hearings for B-R III totally avoided central-station SVG. An angry phone campaign with the C.E.C. from myself, JPL and DOE got a two day generic hearing and report P 300-81-007.....but still no acceptance for central-station considerations in B-R III nor further application of the more prudent alternative criterion.

SVG has since advanced so fast, in part due to the SMUD encouragement by the C.E.C., to now possibly be more prudent than even new geothermal power development. A copy of a Paper, now in review for IEEE Power Engineering Society, is enclosed for your use. In Table II see the SVG plants in conceptual and building stages. SCE is on-line with their first megawatt. SMUD has contracted their first of the 100 MWS. And PG&E has announced a 60 MW SVG in the Carrizo Plain. A late entry for revision of Table II for the July IEEE Summer Meeting is the conceptual plan shown at the February IEEE, a 50 MW SVG by RCA and Public Electric Service of New Jersey. Deemed economic in New Jersey insolation, they estimate their plant at $930/kW installed and on $20,000/acre land at that. That and our long held $850/kW suggest grounds for competition with even geothermal power. For what SVG can mean for California and the Nation see our Grindelwald Letter in P 300-81-007 and Table IV in the enclosed Paper. Can you doubt an impending Golden Era if the Commission will only consider SVG as a possibly more prudent alternative.

However, the Commission's blind spot to its own Administrative Code still work today to exclude the more prudent alternative criterion application to new plant sitings, Seeing an opportunity to try to gain consideration of more prudent alternatives; urging a local petition for delegation of siting authority was the vehicle. We filed our issues in 82-DSA-1 and filed to intervene so that language be included in a Mono County siting code to ensure geothermal siting cases be tested for more prudent alternatives just as required by Commission Administrative Code. I believe that SVG has a fair chance of being the more prudent generation in some or all geothermal cases in our KGRA. But at the least we need apply the test. The Committee rejected intervention and has made no recognition nor discussion whatsoever of this pivotal issue in the directions of development of electric power in our State. Even my Appeal was rejected with no notice of the issue.

Since only Parties (Intervenors, Applicants, Commission) can make filings, direct interrogatories, ask Official Notice and Appeal decisions, the Commission has now chosen preemptive exclusion of an inconvenient or troublesome issue by excluding from Party participation proponents of that issue. However, I will not be frustrated by your selfserving, narrow readings of your Administrative Code. The public must be served. You have a legal obligation to consider public input. We must weigh all new sitings applications against more prudent alternatives for the public convenience and necessity.

May I expect a reply from you or any response from the Commission to our carefully, respectfully and properly proposed issue of More Prudent Alternatives Criterion?

Sincerely yours for California
Energy Decency,

Alfred H. Canada

Alfred H. Canada

Enclosure

SOLAR VOLTAIC GENERATION — AN ASSESSMENT

Alfred H. Canada
Senior Member
The Grindelwald Letter
Mammoth Lakes, CA

Abstract - Central-station photovoltaic generation, a reality in at least two major utilities, is now ready to take its place alongside coal and nuclear as a strategic electric generation option for utility planning of new system capacity. Engineering, licensing, lifetimes, capacity upgrading, financing, construction, and the plant availability/dispatching of Solar Voltaic Generation (SVG) are markedly different from conventional plants. System characteristics, estimated costs, subsystem requirements and Solar Voltaic Generation availabilities are developed. Cost estimates and materials requirements are shown to suggest the SVG requires less materials and capital formation than nuclear or coal in meeting the U.S.A. strategic energy needs at the end of the century.

INTRODUCTION

Only two means of non-fossil fuel electrical generation have emerged to major capacity for utilities in this century, nuclear power and photovoltaic direct conversion of solar insolation to electricity. Other power generation advances have been either improvements on 19th-century technology or steady improvements of the fuel-boiler-turbine-generator. Photovoltaic generation, relegated to sometime in the 21st century by parts of the utility industry and the Secretary of Energy in his 1982 Annual Report to Congress: An intense federally and privately funded research and engineering effort has produced earlier results. The 1974 Project Independence studies [1] recognized the potential of large-scale photovoltaic generation as an alternative to \$4, \$7 and \$11-per-barrel oil. A 1977 conceptual system as a national energy policy alternative [2] contemplated a two-trillion-kWh-annual generation SVG generation. Thus the purposes of this Paper are: to examine the unique requirements and characteristics of the subsystems of a reference design SVG plant; to suggest approaches to system planners in the engineering of SVG into their system's generation mix and to identify areas for engineering; and innovation so that the utility-manufacturing industry can better respond to the SVG option in new generation planning.

SVG reference or starting-point systems for cost estimating, availability planning, materials requirements and specification planning have been slow to appear. Indeed, the far more speculative Solar Power Satellite had a published conceptual reference system as early as 1979 [6]. The concepts in references [2] and [3] were among the first complete plant reference systems. A partial system assessment by an architectural and engineering firm of the balance-of-system (those components not including the photovoltaic generator cells) appeared recently [7]. Outside-the-utility-industry design study contracts have been placed by government laboratories with various aerospace industry suppliers. Designs were prepared for both a fixed flat-plate array field and a Fresnel-lens-concentrator field, both 100-MW plants, with costs, engineering and construction comparisons [8]. The first all-in-the-family contract was placed early in 1982 by the Electric Power Research Institute with a utility A/E contractor [9], for "Integrated Photovoltaic Central Station Conceptual Designs"; a significant step toward SVG acceptance in the utility industry.

SVG systems analyses for the current utility plant construction projects are published in references [10], [11] and [12].

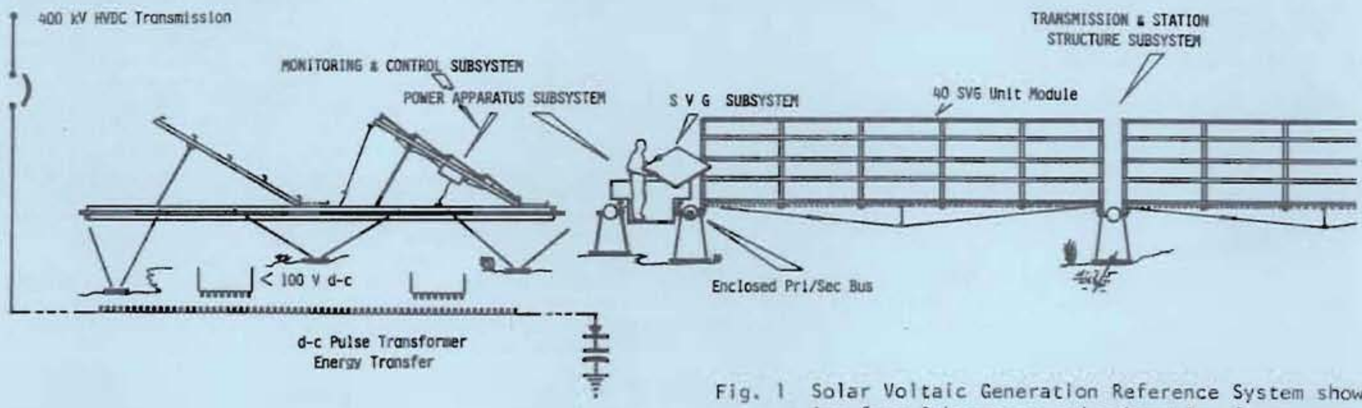

Fig. 1 Solar Voltaic Generation Reference System showing four Subsystems and schematic of one means for energy extraction.

plant by the year 2000; equal to the nation's current electricity consumption. A 4000-megawatt viable reference system, a starting point for engineering design, was published last year [3]. That Paper showed SVG plant availabilities as a function of fuel (solar insolation) for several locations. Notably, in 1982 two major U.S. utilities undertook SVG central-station construction of one-megawatt and one-hundred megawatt plants, respectively [4] and [5]. The first utility megawatt of photovoltaic power went on line at spec-power in January 1983.

Problem, Purpose and Background

SVG plant system engineering, procurement, installation, operation, penetration in a given system mix, availability/load dispatch, revenue return versus construction expenditures, capital formation, lifetimes and generator-to-transmission interfaces are quite unlike conventional central-station

Note: Advance copy of Paper submitted to IEEE Power Engineering Society with the Copyrights for Review for the PES Meeting in July 1983 and Transactions. Please provide critiques, corrections or suggestions to Author, P.O. Box 70, 380136 Grindelwald Road, Mammoth Lakes, CA. 93546.

Organization of Material

A photovoltaics peculiar terminology has been developed by the government laboratories and solid state physics organizations that brought the first 1954 photoelectric-effects cells to the present space and terrestrial power systems. In this Paper and in reference [3], the photovoltaic nomenclature has been adapted to "Definitions for Use in Reporting Electric Generating Unit Reliability, Availability and Productivity" [13]. Also a new term-Solar Voltaic Generation and abbreviation-SVG have been introduced to accompany conventional generation shorthand like LWR, BWR, CFG, MHD, etc.

The reference system SVG, as illustrated in Figure 1, is composed of four Subsystems chosen to conform to existing sectors of the utility engineering and manufacturing industry plus the emerging generator development and manufacturing industry that supply SVG units. The four subsystems were initially selected to simplify the definition and specification of interfaces between the subsystems and to minimize the mixing of different engineering disciplines. The physics, engineering and production technology of photovoltaics are confined to the SVG subsystem. The other three subsystems are well within existing, established utility industry engineering, specifications, procurement, installation and operational capabilities.

Given a specific reference system and location, availability is compared to that of a conventional plant. Materials, costs, complexity and size of undertaking are estimated for gigawatt plants in the utility industry or for vast federal power projects having major strategic impact on the energy needs of the United States.

THE SVG SYSTEM

The characteristics of the reference system are shown in Table I from reference [3]. A 4000-MW Installed Nameplate Capacity (INC) is used to just equal the annual generation of the 1500-MW Cal-Coal plant now through the Notice of Intent phase of licensing for the same region of California. In a 1980 Intervention in the licensing process (79-NOI-3, California Energy Commission) and parallel Shareholder Proposals [14], such plant characteristics and subsystem breakdowns were used to urge consideration of a 4000-MW SVG plant alternative to the proposed 1500-MW Cal-Coal and to show a somewhat lower estimated busbar cost for the SVG alternative than for the planned Cal-Coal plant. In an interesting corporate response to the Shareholder Proposals [14], a 1982 estimate was given at $2700/kW for a "mature" SVG system.

The land, materials and costs estimates in Table I are based on current commercial photovoltaic generators, measured insolation (fuel), and cost approximations as discussed for the various subsystems. The reference system characteristics are based on a near-term SVG unit (one square meter as illustrated) Installed Nameplate Capacity of 0.125 kW-INC, forty SVG units per stand or module, tilted to the south 30 degrees, two-meter horizontal spacing row-to-row and reflector augmentation on the north slope of the modules. For a Daggett, California site, see references [3] and [22], the maximum irradiation is 1.05 kW/m^2 on the 32 million SVG units. For both maximum and total annual irradiation, a 6% plant loss is assumed for power handling, degraded SVGs, station power, etc. Then the maximum and total annual values, reduced by six percent, are used to determine GMC, GAAG and Gross Capacity Factor (GCF). Finally, at some $500/kW or $62.50 per SVG unit, the 30-year average replacement cost is 7.9 mils per for the kilowatthours generated by each SVG over the assumed life.

Table I

SOLAR VOLTAIC GENERATION PLANT CHARACTERISTICS

Electrical [13]	
SVG Unit, one square meter	0.125 kW (INC)
Installed Nameplate Capacity (INC)	4000 MW
Gross Maximum Capacity (GMC)*	3948 MW
Gross Actual Annual Generation (GAAG)*	8.45 billion kWh
Gross Capacity Factor (GFC)*	0.244
**Site fuel dependent, see Fig. 2 and ref.* [3]	
Areas	
Forty SVG Units Modules	33 ft. x 18 ft.
Modules per Square Mile	42,924
Plant Area (at 215 MW/mi^2)	18.6 mi^2
	11,904 acres
Materials **	
Steel (at 2000 lbs/module)	200 tons/MW
Silicon (for 4-12 mil thick cells)	2.4-7.4 tons/MW
Copper (100v. d-c Module to 400kV d-c bus)	0.17 tons/MW
Glass	50 tons/MW
Aluminum (SVG Unit Frames)	21 tons/MW
Unit Capital Costs, current dollars	
Land (at $250-$1000/acre)	$0.75-$3.00 /kW
SVG Subsystem ($380/kW + $120/kW Install)	$ 500 /kW
Trans & Stat Structure Subsystem	$ 200 /kW
Power Apparatus Subsystem	$ 50 /kW
Monitor & Control Subsystem	$ 22 /kW
Utility Engineering & Construction	$ 75 /kW
TOTAL	$ 850 /kW
Operating & Maintenance Costs	
Fuel and Fuel Charges	- zero -
Cooling & Station Water	- zero -
O & M (unattended plant)	$3/kW-Yr
SVG Unit, 30 yr ave replacement/upgrade	7.9 mils/kWh

*** Materials comparison estimates* [3][24]. *Note the ratio of GCFs, 0.60 for nuclear and coal versus a GCF of 0.24 for SVG...a 2.5 multiplier to apply to the SVG materials.*

	Nuclear	*Coal*	
Concrete	*300-400*	*200-300*	*tons/MW*
Copper	*0.8*	*0.8*	*tons/MW*
Steel	*7-36*	*20-60*	*tons/MW*
Fuel (30 yr supply)	*5.6*	*58,000*	*tons/MW*

In Table II the characteristics of three recent reference systems or the balance-of-system portions [7] and [8] are compared to the Table I reference system data, insofar as data are available from those sources.

The most notable engineering feature of SVG central-station is the vast number of like components that must be installed as the plant capacity is enlarged. For example, to install the 4000-MW reference system during a six-year construction phase (similar to the construction phase proposed for the 1500-MW coal-fired plant), nearly 800,000 Transmission and Station Structure modules must be installed. This requires automated steel-mill fabrication to field-erection at a rate of 365 modules (365 tons of steel) per day, seven days a week for six years. This need for innovative, automated, mass production and installation has been recognized by the Sacramento Municipal Utility District for their plant increments beyond their first megawatt [5].

Three characteristics, unique to SVG central-station, can have important impacts on new capacity planning: 1) Century, Plant-Lifetimes; 2) Incremental, Redundant Construction; and 3) Immediate Revenue Payback.

Century, Plant-Lifetimes are inherent in the Station Structure, Power Apparatus and Supervisory Control Subsystems. As with hydroelectric, irrigation canals and transmission systems, the engineering, financing and amortization can be predicted on century lifetimes. There may never be decomissioning costs. The SVG units may be replaced every 30 years, as indicated in Table I, or more often as SVG units with improved INCs and GAAGs become available . . . increasing the capacity and the generation of a given plant over its lifetime.

Incremental, Redundant Construction allows a single site licensing with banked area for expansion of capacity for a quarter to half century of a utility's marketing of its product. There is a built-in ongoing proof-of-concept and shake-out of warranties in incremental SVG construction. As already noted in the SMUD plant engineering [5], the second and subsequent megawatts of SVG unit procurement will learn from the already-under-contract first megawatt, resulting in new competitive procurements. The impact on the normal start-to-finish involvement of an Architectural and Engineering contractor is interesting. Rather than apply that A/E's six to sixteen-percent fee and contingencies to the entire plant (see Table II), the A/E task, if at all, is completed after the first megawatt proof-of-design. From then on the utility replicates the initial plan as capacity is needed. Ideally, manufacturers in each subsystem area will develop and test proprietary subsystem elements, permitting the utility engineer to order one-of-these and four-of-those from catalogs. A large-scale "energy-gathering system" SVG procurement by a utility is much more like its "energy-distribution system" procurement than like another multi-gigawatt nuclear or coal plant project.

Immediate Revenue Payback (IRP) of an incremental, going-on-line SVG provides interesting financial possibilities; perhaps obviating a need for CWIP (Construction Work In Progress) charges in the rate structure. Given two plants, an SVG and a conventional coal or nuclear, each having capacity to produce the same annual generation, having equal plant costs exclusive of debt service and interest during construction; the SVG produces revenue as the first increment goes on line—almost before the "30-day-net" bills due on that increment. In a case analyzed in reference [3] for a 1500-MW, 0.60 GCF at $2260/kW coal plant, a current average for mid-1992 completion, and a 4000-MW, 0.24 GCF at $850/kW SVG, both at 15% cost of capital, 100 mils/kWh going into fixed charges pays off the SVG plant in the 12th year and the coal plant in the 26th year. The coal plant cost and interest total some four times that of the SVG. And no fuel charge is added for the SVG.

For SMUD's 10-year construction of a hundred-megawatt plant this IRP feature of SVG annual revenue is expected to exceed annual expenditure for incremental expansion somewhere around the seventh year when the plant is about one-third installed [5].

Finally, IRP upon moving SVG to the ratebase and revenue producing as soon as installed is an advantage to municipal, PUD and co-op owned utilities in attracting revenue-bond financing or improvement fee financing assessed to service area building and demand growth.

It is important to recognize that conventional plant economics don't fit in SVG economics. Immediate revenue payback as the SVG plant goes on line incrementally can be used to reduce the cost of capital, the capital required, or the fixed charges rate applied in rate setting. An SVG plant has a lifetime approaching a century. SVG has ZERO-FUEL-COST. Plant losses, plant power needs and even long-distance transmission losses are tied to capital costs of the displacing capacity rather than to escalating fuel costs. Operating costs are lowered since very large fixed-array plants should operate unattended. Installed Nameplate Capacity, Gross Maximum Capacity and Gross Actual Annual Generation all increase with SVG subsystem retrofits during the long plant life, unlike the slow degradation of the conventional steam-generator plant. Finally, third-party debt-financing for SVG construction to sell power to regulated utilities has already been undertaken by private entrepreneurs [4] and may soon be done by wholly owned subsidiaries of regulated utilities.

Solar Voltaic Generator Subsystem

Generator units for the reference system are illustated in Figure 1 as one meter square multi-cell panels; a possible sizing for convenience in manufacturing, shipping and one-man handling for plant installation and servicing. Beyond conforming to an external frame-size standard, manufacturers could innovate any manner of photovoltaic technology within the SVG frame, e.g., storage solar cells, tandem materials cells, thermionic converters, radiation and cooling schemes, integrated control circuitry, etc., in order to enhance the Installed Nameplate Capacity and Gross Actual Annual Generation of their product. A manufacturer could devise optical surface treatments within the standard frame, perhaps even simple sun-tracking in order to increase the potential GAAG of his product.

Photovoltaic solar-cell arrays are electrical generators that consume solar irradiation as fuel, make no noise, pose no health hazards and produce no waste products. How tightly the round, square, strip or rectangular cells are packed and their conversion efficiencies determine the Installed Nameplace Capacity of the SVG unit.

Table II COMPARISON OF SVG REFERENCE SYSTEMS FROM SOURCES NOTED, WITH SELECTED SUB-ITEMS COSTS FROM SOURCES DATA

	SVG Table I [3]	Flat-Plate [8]	Fresnel [8] Concentrator	Flat-Plate [7]	Fresnel [7] Concentrator	Tracker[11] Flat-Plate	Tracker[10] Flat-Plate	Flat-Plate [10]
Location	Daggett,CA (assumed)	RedRock,AZ (assumed)	RedRock,AZ (assumed)	n.r.	n.r.	Hesperia,CA Lugo Substa.	Rancho Seco,CA	Rancho Seco (assumed)
Type	Fixed	Fixed	2-axis	Fixed	2-axis	2-axis	1-axis	Fixed
INC, MW (op date)	4000	100	100	(100)	(100)	1 ('83)	100 (1-'84) ('94)	100
GCF	0.24	n.r.	n.r.	*[4]*	*[4]*	n.r.	0.30	n.r.
Area, mi^2	18.6	1.56	2.28	n.r.	n.r.	0.3 (20 a)	1.4	1.4
Packing, MW/mi^2	215	64	44	(51-64)	(125-246)	32	71	71
Generator Unit, m	1 x 1	1.32x1.32	0.43x1.47	(0.75-1 m^2)	n.r.	0.3x1.22	0.3x1.22	0.3x1.22
INC or Eff.	0.125kW(12.5%)	12.2	17.7	(0.1kW/m^2..*[3]*..0.16/m^2)		11.07	11.07	11.07
Units/Module	40	18	60	n.r.	60	256	256/drive	256
Modules, m (l.h.)	10x5.5	11.9x2.6	13.5x3.3	11x2.4	13.5x3.3	95 m^2	2.4x43	2/4x43
SUBSYSTEM Estimated Costs, Dollars per kilowatt of Installed Nameplate Capacity ('82$s).......								
S.V.G.	$500	$1000-$3500	$1000-$3500	n.r.	n.r.	n.r.	$ 4950 Bid	$ 4950
Power Apparatus	$50	$50-$500	$50-$500	$143	$195	n.r.	$64	$64
Monitor & Control	$22							
Trans&StaStructure	$288	$1024	$903	$580	$381	n.r.	$926	$267
Proj.Devel.	($78 w.land)	$93	$83					
Mgt.Lic.Test.	($75)	($17)	($16)			($1869/kW for first megawatt)		
A & E	-0- *[1]*	($76)	($67)	($35)	($23)			
Proj.Construction		$930	$820					
Foundations	-0- *[2]*	($110)	($75)	($53)	($106)	n.r.	($133)	($66)
P-V System	-0-	($554)	($482)					
Adjust&Contingen.	*[1]*	($173)	($152)	($116)	($76)			

Notes: *[1] A&E and Contingencies not applied to successive plant increments, [2] No concrete foundations, footing-trenches nor cable-trenching, [3] Assumed from ref.[7] to reconcile area B.O.S. costs to costs per kilowatt, [4] B.O.S. efficiencies est. at 80% in ref.[7] by multiplying nine 2 and 3 significant figure Subelements, [n.r.] not reported.*

A number of materials and processes are used to fabricate photovoltaic cells, with possible future cell conversion efficiencies of 16%, 22% or 35%, INCs of 0.160, 0.220 and 0.350 respectively, enabling future step-up in the capacity and generation of central-station SVG plants that are started today.

The INC ratings of a number of commercially available SVGs, normalized to one meter square, are shown in Table III. The "Block Purchases" by DOE/-JPL, performance test data and procurement sizes are shown along with data extracted from some commercial specification sheets. Suppliers use various cell-packing factors. None now supplies a panel measuring just a square meter as in the SVG unit suggested for the reference system. However, the normalization used in Table III simply extends the specific design to a square meter, a step easily accomplished by the manufacturers if so specified in an SVG subsystem procurement. Where data are available, the packing factor or percent of the panel occupied by solar cells is shown. Block purchases and test data are shown as procured and tested at the Jet Propulsion Laboratory, Low-Cost Solar Array Project (LSA), [15], [16], [17] and [18]. Letter designations for various manufacturers are consistent with data and companies as reported in the references. The normalized SVG INCs indicate progress since Block I.

Early concerns with "energy payback time"—how long it takes the resultant generator to generate the energy required for its manufacture—have become a non-problem. Even the single-crystal silicon cells, the large energy consumer in crystal growth, are projected by Jet Propulsion Laboratory to be only 0.6 to 1.1 years by mid-decade. Thin-layer amorphous silicon cells with less silicon are even less of a problem. Manifestly, return of investment is the more correct measure of the energy portion of the price of a cell or a system.

The LSA Project established testing specifications on radiation, thermal and mechanical characteristics for the flat-plate, non-concentrating photovoltaic or SVG unit [19]. The "module peak-power rating" or Installed Nameplate Capacity is determined under a radiant fuel input (insolation) of one kilowatt per square meter, a spectral content as if filtered through an air mass of 1.5 attenuation, with cells at 25°C. Based on Table III data and a production packing factor of 0.90 to 0.95, an INC of 0.125 kW is reasonable, is anticipated and is used for the reference system.

Reporting a recent competitive procurement for the SMUD Project [5], three U.S. concerns entered proposals. The award for the first megawatt went to a supplier on the basis of 11.07% panel efficiency (equal to a square meter SVG unit having a 0.1107 kW-INC), a one-by-four-foot size and a price of $4950/kW. The three suppliers estimated production capabilities were 3 to 8 megawatts per year. Approximately 60 companies are now manufacturing photovoltaic panels in 20 different countries. Note the inclusion of a module manufactured in Shanghai, P.R.C. exhibited recently [20].

Lifetimes of the silicon-cell generators continue to be a roadblock for SVG central-station. The difficulty in getting lifetimes useful to utilities is widely reported. Much of the problem obtains from packaging 50- to 100-year silicon cells in 5- to 10-year polymers, the solar panel lifetimes conclusions springing from the rapid photodegradation of the polymers used as encapsulants, substrates, UV absorbers, back-covers, primers, adhesives, edge-seals, etc. in packaging the very long-life cells. Most of the current DOE program in "environmental isolation" packaging is devoted to R&D on the photodegradation of polymers. There is no need to continue to hobble central-station SVG with attempts to use 5- to 10-year life polymers when hermetic sealing in glass, as already pursued by some manufacturers, could provide 50- to 80-year lifetimes for SVG units.

Three needs exist in the Solar Voltaic Generator: 1)product engineering to bring the cell packaging of very long-life silicon cells to industrial standards suitable for long-lifetime central-station use of the order of 50 to 100 years; 2) high-rate mass production technology with the attendant cost reductions; and 3) research and product development to continually improve the INCs and GAAGs of Solar Voltaic Generators. More specifically, there is a need . . . to engineer some standard package such as the square meter SVG used in the reference system, to develop IEEE Standards for an SVG unit, to encourage manufacturers' achievement of the highest Installed Nameplate Capacities, to innovate optical treatments to provide the highest Gross Actual Annual Generation for different site-dependent solar irradiance characteristics, to innovate radiation and convection cooling schemes minimizing temperature rise and to achieve long-life packaging. Beyond these basics, the SVG designer-manufacturer needs to design regulation, hot-spot protection, fault detecting and monitoring circuitry into the SVG unit to accommodate optimum energy transfer, supervisory control and intermixing of SVG units of different vintage and manufacture.

Packaging affects lifetimes, cost, irradiation acceptance and temperature rise, directly impacting the SVG's INC and GAAG in plant applications. The electrical manufacturing industry already has the experience to mass produce hermetically sealed, long-life packaging, applicable to SVG units, as fast as they now turn out light bulbs. As a cost comparison example, solar cells could be packaged in a manner similar to fluorescent tubes. Consider that a four-foot tube is about a third to half of a square foot cross-section, could hold about 4.8 watts of cells and retails locally in jobber lots for about 80 cents each. That is $2.40 per square foot or $25.44 for a square-meter area of the SVG unit . . . and that includes profit, shipping, warranty and the local hardware store's markup. To this add about $7 for 0.5 kg. of P-V grade silicon (DOE projected price) and about $15 for the processing. The SVG units, mass produced like light bulbs, could clearly meet our Table I estimate of either $500/kW installed or $62.50 each at the local hardware store. This is only an order of magnitude price improvement on the recent megawatt procurement, an improvement certainly accommodated through the introduction of highly competitive, high-speed mass production. Over 300 million fluorescent tubes are produced annually in the United States, 1500-MW potential in SVG units production, with no great notice of critical impacts of materials or production facilities.

Transmission and Station Structure Subsystem

The mechanical structure is shown in one form in Figure 1 as a steel-frame stand to hold four SVG units. Similar in engineering, manufacturing and installation to utility substation and transmission structures, innovations will be needed for SVG for high production, shipping, erecting and serviceability of the generator, power and supervisory subsystems held by the structure. This subsystem could stand for a century or more as SVG unit replacements and upgradings are made for as long as the solar fuel is available.

The sheer number of SVG stands involved in a very large plant requires Station Structure designs that allow integrated mill to transportation to field erection with a minimum of field labor. For just the reference system to be built in six years would require an installation rate of more than 2500 modules (40 SVG units each) per week. For many western desert locations, trenching for concrete bases, trenches for cables, and the surface access to several square miles of SVG plant ensure irreparable damage to the fragile desert. Once disturbed, the assured dust storms and sand damage pose unnecessary O & M costs. An integrated, all-steel Station Structure including transmission and service-car access, such as illustrated in Figure 1, is necessary. It is procured from the steel maker just like a bridge or the frame for a skyscraper. At current mill prices for the frame for corrosion-resistant steel of about $600/ton, $250/ton shipping and $150/ton for erection, the subsystem estimate is determined for Table I. This $25/m² of active SVG units can be compared to $28.60/m² priced out by an A/E contractor [7] for a field fabricated, aluminum stock sections frame with concrete piers and no provision for integrated rail-car access nor integrated busways for power.

In the subsystem illustrated, folded components might be transported in the field on the existing structure, set in place and foot elevations adjusted with little or no need for personnel or equipment to operate on the ground. Once in place explosive anchors could be used to fix the stands.

A number of stand-alone designs have been proposed, some on single posts set in concrete for one- or two-axis rough tracking of the sun position. Trade-off analyses have been conducted to weigh the cost of one- or two-axis mechanical tracking versus the fixed-array approach as in Figure 1, [7], [12] and [21]. The reported gain in tracking is 20% to 40% in Gross Actual Annual Generation, depending on location, scattering to direct ratio sky conditions, latitude of the site and marginal value of the capacity early and late in the day. The 92 m² of solar panels trackers installed at the Lugo, CA substation are estimated to consume about one percent of the GAAG [12] and of course require more maintenance than does a fixed array.

Advanced designs in SVG units can include optical surfaces enhancement of morning and evening collection, thermal-activated rough tracking within the SVG frame or the array stands given a fixed east or west tilt to bias temporal generation to better fit system loads. As stated in the reference paper, at today's SVG unit prices, the two-axis tracking as installed at the Lugo substation is definitely more cost effective than fixed-flat-panels, with the increased annual energy production per square meter more than compensating for increased array field costs. The question is whether this is still a cost-effective option when SVG unit prices have dropped by a factor of ten [20].

Power Apparatus Subsystem

Transformers, switch-gear, inverters, protective devices, etc. comprise the power subsystem. Its purpose is to extract energy from a vast array of SVG units and deposit that energy in an appropriate transmission to a load center. This subsystem offers interesting engineering innovation opportunities in the power apparatus industry to reduce copper and power losses, to keep to low SVG subsystem potentials exposed and to ground, to provide insolation of SVG modules for reducing fault and shadow runaway current/temperature problems, to allow mixing of different electrical characteristics SVG units in the same plant, and to simplify lightning protection.

For few kilowatt, dispersed, grid-connected rooftop SVG power supplies, a line or self-commutated inverter is indicated to utilize the photovoltaic d-c output. However, gathering d-c energy from several million generators spread over many square miles invites other approaches and innovation by the utility manufacturing industry.

As shown in reference [3], the SVG unit output power varies with insolation input (fuel-rate), temperature rise and d-c load resistance. Moreover, to obtain maximum power the d-c load resistance must be adjusted for variations both in fuel-rate and in temperature rise. Design of an electrical network to accommodate thousands of such generators, to accommodate fuel-rate and temperature rise, and to provide fault, transient and lightning protection offers opportunity for new concepts in SVG system energy extraction.

A possible approach from references [2] and [3] and illustrated in Figure 1 uses isolation transformer energy coupling at each low-voltage 5 kW SVG module to an HVDC bus that serves as each transformer primary and a common secondary. The HVDC cable in the bus way is simply a helix conductor instead of a normal straight-through conductor surrounded by a series of helical conductors isolated from the HVDC. Simply, 1540 primaries (one for each 5 kW module) are coupled to the single cable secondary, for example through a d-c pulse transformer energy transfer. The cable-secondary is at HVDC transmission line potential, grounded through a rectifier and capacitor. Placing an unpowered string on the transmission line—in this case, 400 kV d-c to ground—the string goes to and floats at the tie point potential as determined by the HVDC transmission line loading. As energy charges from the many SVG module primaries are deposited in the cable secondary, it feeds energy to the HVDC transmission line . . . voltage self-regulating. Surely, if the electrical industry can contemplate induction transfer of 5 MWs over 22,000 miles to a rectenna on earth from a photovoltaic Space Power Satellite [6], an induction energy transfer from isolated, low-voltage groups of generators to a HVDC bus is within the industries' grasp.

Table III

INSTALLED NAMEPLATE CAPACITY...SOLAR VOLTAIC GENERATORS

Power rating (INC)(W_{peak}) irradiation: 1 kW/m², air mass 1.5, cell temperature 28°C.
Temperature Rise (Efficiency Fall-Off): NOCT (Normal Operating Cell Temperature) conditions:- Irradiance, 0.8 kW/m² (Blocks II,V & some specs), 1 kW/m² (III & IV), Air Temperature, 20°C, Ave. wind 1m/sec.

Procurements & Mfg.Catalg	Size m²	Power W_p	Packing Factor	NOCT °C	SVG-INC watts
Block I 1975 (58 kW buy)					
A	0.09	5.4	0.52	-	57
B	0.23	14.5	0.57	-	63
C	0.13	9.3	0.60	-	70
D	0.08	5.4	0.48	-	66
Block II 1976 (123 kW buy)					
A	0.17	10.2	0.63	(43)	60
B	0.45	33.9	0.69	(46)	75
C	0.34	22.0	0.55	(47)	65
D	0.45	30.7	0.52	(41)	68
Block III 1977 (205 kW buy)					
A	0.17	10.7	0.65	49	64
B	0.45	35.6	0.69	52	78
C	0.34	21.8	0.57	53	64
E	0.27	22.2	0.67	57	82
F	0.34	26.5	0.63	61	79
Block IV 1980 (14 kW buy)					
B	0.72	61.9	0.76	46	86
C	0.77	63.7	0.85	56	83
E	0.37	35.9	0.77	47	97
F	0.43	38.6	0.76	56	88
G	0.84	85.7	0.74	55	102
H	0.54	34.6	0.62	56	64
J	0.50	58.0	0.84	56	116
Block V 1982					
E	0.74	72	0.72	49	97
K	1.50	90	0.90	61	60
S	2.02	176	0.91	47	87
L	1.44	114	0.75	42	79
C	1.32	108	0.89	49	82
J	0.67	78	0.82	49	116
From Catalog Sheets					
C	0.84	65	0.86	-	77
E [10]	0.37	41	-	44	111
F	0.43	40	0.77	(56)	93
G	0.83	80	0.72	-	96
H	0.144	8.9	0.55	-	62
M *	0.49	60	-	(44)	122
P.R.C.	0.19	9	-	-	47

* *Tentative Specification*

The copper requirements shown in Table I, based on this HVDC bus approach, are derived in reference [3]. For a many-square-mile plant the copper use can be substantial, inviting innovation beyond thousands of inverters. Energy transfer to HVDC transmission as near each module as possible, as shown in Figure 1, would seem an obvious direction for development.

Monitoring and Control Subsystem

The central computer supervisory control for unattended operation of the entire SVG plant should provide functions such as: pulse or frequency control for the energy transfer from generator units to transmission, digital address polling of generator unit electrical status, plant load assumption and shedding, fault sensing and generator performance. A coaxial control wire from the central processing unit to the field of generators can readily accommodate the data rates for these control functions. In future SVG unit manufacture, an integrated circuit can be part of the square meter SVG unit to include these control functions and a store and pulse circuit to accumulate energy and dump it into a transmission bus on command.

System Availability

A plant availability chart is derived in Figure 2 from hourly, average-day each month values from [2] for the Daggett location and summed for the

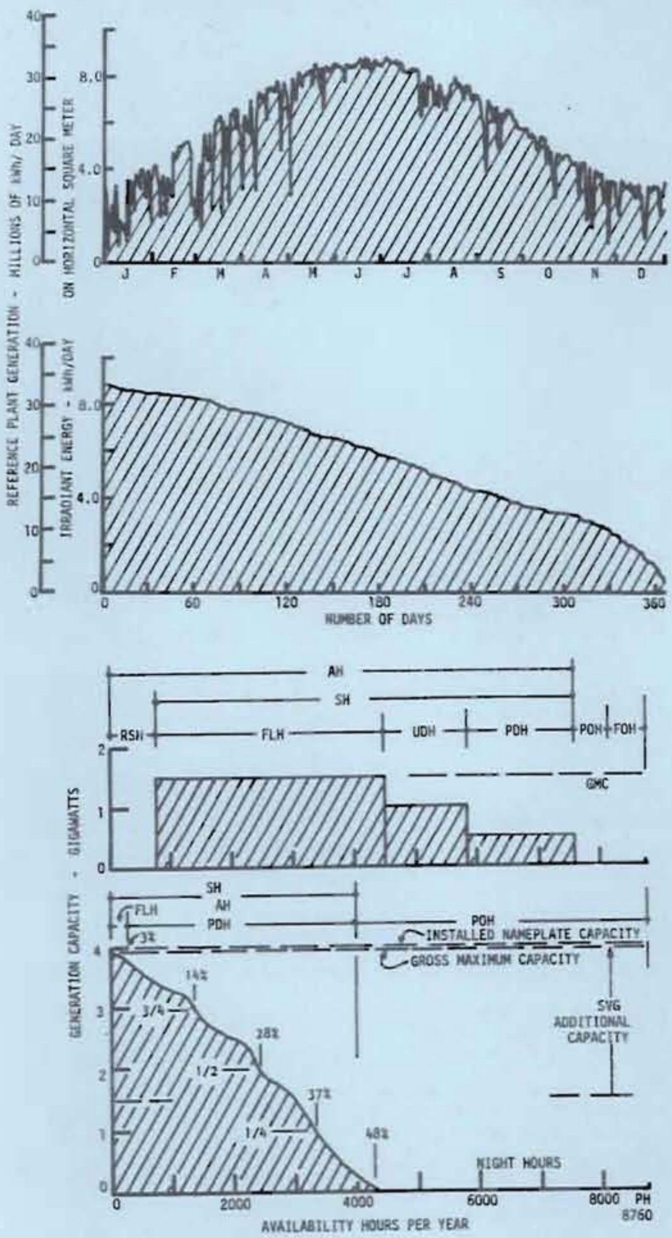

Fig. 2 Fuel-Supply, Generation-Days (measured at site, in 1978 [25]), and Availability-Hours for the SVG Reference System, 4000 MW GMC, 0.24 GCF compared to a fossil-fuel-fired plant at 1500 MW GMC, o.64 GCF; both plants having a GAAG of 8.45 billion kilowatthours.

hours per year exceeding any particular value of irradiant power. The irradiant power scale is adjusted for a 32-million SVG plant, less the 6% assumed plant losses. The Full Load Hours (FLH) are 273.6 hours in excess of 1 kW/m². Figure 2 includes an availability chart of a typical fossil or mineral-fueled steam generation plant of the same GAAG. The various availability hours designations conform to the time definitions in reference [13].

Once in a utility's generation mix, solar-electric at zero-fuel-cost is always the next cheapest kilowatthour to dispatch in the system, when available. Generation availability is not only when the sun shines. As shown in reference [3] even overcast days with precipitation can provide a third to a half as much generation as a clear day. We assume full use of the solar generation to displace fossil and mineral fuel use and to extend the life of even base-load generation put on spinning-reserve. For the SVG case it is assumed that Service Hours (SH) equal Available Hours (AH) and that there are no Reserve Shutdown Hours (RSH). Maintenance is performed during Planned Outage Hours (POH) or, in the case of the low-exposed-voltages reference system, on SVG units during full-power operation. Forced Outage Hours (FOH) are not applied to the SVG availability curve. With isolated energy transfer at each 5 kW module there is little possibility of total plant breakdown. With adequate weather prediction (see discussion in reference [3]), Solar Voltaic Generation should not be subjected to Unplanned Derated Hours (UDH). Of value to some systems is the large reserve capacity around midday over that of an equal annual generation conventional plant, a 3948-MW Gross Maximum Capacity versus a 1500 GMC for the coal plant illustrated. For the Daggett example shown, there are about 3000 Available Hours per year at capacity exceeding 1500 MW.

STRATEGIC GENERATION

What can Solar Voltaic Generation mean to U.S.A. and world strategic generation? In short, it is a potential, vast, prime electrical energy source that we know how to develop, that we have commercially applied in at least two electrical utilities. The general problems for utilities and impacts on their rate-payers—the escalating cost of fuels, fuels control and parity pricing by the oil company owners, an uncertain supply of natural gas, and effects of compliance with numerous environmental and regulatory requirements—are offset in the SVG plant by zero-cost, clean solar fuel that will be at the plant site for as long as needed . . . sans OPEC, sans strikes, sans fuel severance taxes and sans depletion. Once the capital is invested, SVG can be viewed as an "oil well" with unlimited reserves, making the SVG utility a basic prime energy supplier. SVG on an area equal to that of the great Ghawar, Aramco, 5-million-barrels-per-day oil field in Saudi Arabia would provide as many kilowatthours as obtained from that oil production. Insolation as a utility fuel is cheaper, more abundant at the electric generating plant and more benign in the environment than any other utility fuel has ever been.

The National Energy Policy Plan of July 1981 and DOE's 1982 Reports to The Congress [23] spell out, "photovoltaics not projected to make a significant contribution during the next forty years" and "commitment to uranium and coal." Data from the NEPP-III is presented in Table IV as an energy balance matrix, prime fuels IN and useful work OUT, for 1980 and for the midrange 2.8% GNP annual growth rate for the year 2000. Note the projected large increases in coal and uranium production from 1980 to 2000, 18.9 to some 42.0 Quads for coal and from 2.7 to 10.6 for uranium.

Our DOE energy planners neglected to consider the impact of a large input of solar-electric prime fuel. Unlike the generation losses in coal and nuclear fuels conversion to electricity, about 26 Quads loss in 2000, the rest being transmission and distribution losses, etc., some 10.3 Quads of SVG electrical generation is all input to the consumption sectors. Moreover, it allows a 3.6% GNP annual growth.

That 10.3 Quads for SVG-2000 impacts the coal-CO_2/acid rain atmospheric problems, the federal policy for continued growth of exorbitantly expensive nuclear power, the oil companies' and OPEC's lock on conventional utility fuels, and the NEPP-projected imports of oil and gas for the year 2000, three and two Quads, respectively. Our coal use would increase only 16 percent. Nuclear use would hold at the 1980 level. The U.S.A. could become an oil-exporting nation at a domestic production less than its present rate.

The additional coal-nuclear capacity in the NEPP-2000 scenario is about 470,000 MW versus an additional 35,000 MW in coal capacity and 1,378,000 MW in SVG for the SVG-2000 scenario. Using midrange 1992 completion costs of $2260/kW for coal ('82$s) and $3262/kW for nuclear [2], the SVG and coal option capital cost is about $1.26 trillion versus the NEPP coal-nuclear option add the capital cost and materials for the needed additional fuel infrastructure. The SVG materials shown in Table I are compared to those in a same-annual-generation nuclear plant in reference [3], requiring somewhat fewer materials for the SVG plant. In terms of national effort, raising capital, and the comparable materials, the SVG-2000 scenario looks more tractable. One way or another, the U.S. will build a trillion dollars worth of new generation before 2000. It is reasonable to expect that we could expend that effort and material as easily on either option, the NEPP-Coal/Nuclear-2000 or the SVG-2000.

If the 1,378,000 MWs of SVG were concentrated in one area at the Daggett, CA level of insolation and 25% capacity factor, it would require an area of only 80 miles by 80 miles (a square area 129 km by 129 km). Tied to HVDC transmission, typically thousand-mile runs, this even suggests northern Mexico SVG electricity export to the U.S. and possibly northern Africa export to Europe.

SVG is now available to utilities to expand generation and power

Table IV SOLAR VOLTAIC GENERATION IN THE NATIONAL ENERGY POLICY PLAN [22], IN QUADS OF ENERGY (D.O.E. 7/81)

Indicia:

1980 NEPP – SVG 2000 Alternative at 3.6% GNP Annual Growth
NEPP 2000 NUC-COAL Projection at 2.8% Annual Growth

** Difference, INPUT less DIRECT and ELEC.GEN. input into Strategic Reserve*

ONE QUAD = 1 Quadrillion Btus
= 293 Billion kWhs
≅ 167 Million BBLs-Oil
≅ 50 Million Tons-Coal
≅ 966 Billion cu.ft.-Gas
≅ From 645 mi² of SVG

PRIME FUELS	DOMESTIC PRODUCTION	IMPORTS (EXPORTS)	INPUTS midrange	SECTORS DIRECT	- - - CONSUMPTION BY SECTORS TRANSPOR.	INDUSTL.	COMMERC.	RESIDEN. - - -	ELECTRIC GENERATE
OIL	$20.5-^{20.0}_{20.0}$	$13.3-^{(2.5)}_{3.0}$	$^{*}33.8-^{17.5}_{23.0}$	$^{*}31.2-^{16.5}_{23.0}$	$18.0-^{13.2}_{17.3}$	$7.5-^{2.0}_{4.1}$	$3.1-^{1.1}_{1.4}$	$2.6-^{0.2}_{1.2}$	$^{*}3.0-^{1.0}_{0}$
GAS	$19.8-^{18.0}_{18.0}$	$1.0-^{0}_{2.0}$	$^{*}20.8-^{18.0}_{20.0}$	$^{*}16.7-^{16.6}_{20.0}$	$0.6-^{0.5}_{0.7}$	$8.5-^{9.1}_{12.6}$	$2.3-^{2.3}_{2.8}$	$5.3-^{4.7}_{3.9}$	$^{*}3.8-^{1.4}_{0}$
COAL	$18.9-^{36.1}_{42.0}$	$(2.4)-^{(12.3)}_{(5.9)}$	$16.5-^{23.8}_{36.1}$	$3.5-^{8.9}_{7.5}$	$- -^{-}_{-}$	$3.3-^{8.1}_{7.1}$	$0.1-^{0.6}_{0.2}$	$0.1-^{0.2}_{0.2}$	$12.1-^{14.0}_{28.0}$
NUCLEAR	$2.7-^{2.7}_{10.6}$		$2.7-^{2.7}_{10.6}$						$2.7-^{2.7}_{10.6}$
HYDRO/GEOTHER	$3.2-^{4.3}_{4.3}$								$3.2-^{4.3}_{4.3}$
RENEWABLES &	$1.8-^{5.4}_{5.4}$			$1.8-^{4.2}_{4.2}$		$1.6-^{2.5}_{2.5}$	$- -^{1.0}_{1.0}$	$0.2-^{2.0}_{0}$	$- -^{1.2}_{1.2}$
S.V.G.	$0-^{10.3}_{0}$			$0-^{10.3}_{0}$	$0-^{0.6}_{0}$	$0-^{6.0}_{0}$	$0-^{1.7}_{0}$	$0-^{2.0}_{0}$	$- -^{-}_{-}$
INPUT FROM ELECTRIC GENERATION WORK . .				$\underline{7.1}-\underline{^{7.1}_{12.0}}$	$- -^{-}_{-}$	$2.8-^{2.8}_{4.7}$	$1.8-^{1.8}_{3.1}$	$2.5-^{2.5}_{4.2}$	
TOTAL INPUT TO SECTORS					$18.6-^{14.3}_{18.0}$	$23.7-^{30.5}_{31.0}$	$7.3-^{8.5}_{8.5}$	$10.7-^{10.1}_{10.0}$	$24.8-^{24.8}_{44.7}$
LOSSES					$16.4-^{12.0}_{15.9}$	$6.6-^{7.5}_{10.0}$	$2.2-^{1.6}_{2.2}$	$3.3-^{1.9}_{2.5}$	$17.7-^{17.7}_{32.0}$
USEFUL WORK					$2.2-^{2.3}_{2.1}$	$17.1-^{23.0}_{21.0}$	$5.1-^{6.9}_{6.3}$	$7.4-^{8.2}_{7.5}$	$\underline{7.1}-\underline{^{7.1}_{12.0}}$

marketing to move again to those halcyon days of "Ready Kilowatt" bill-stuffers. SVG in federal power projects such as Bonneville Power Authority and TVA can renew the economic benefits of abundant, affordable electric power.

CONCLUSIONS

Utility central-station Solar Voltaic Generation is a reality in 1983. As a prime electric fuel in our national energy plan, SVG has the potential to make the U.S. an oil-exporting nation by the turn of the century, while at the same time requiring but little increase in coal-fired generation and no increase in nuclear generation capacity.

An SVG central-station plant is a large-scale "energy-gathering system" that can be procured by the utility as demand grows, incrementally as thousands of redundant subsystem components; being more similar to a utility's "energy-distribution system" engineering and procurements than to the procurement of another multi-gigawatt nuclear or coal plant.

Conventional plant economics and rate structuring do not fit SVG economics. Immediate revenue payback as the SVG plant goes on line incrementally can be used to reduce the cost of capital, the capital required or the fixed charges rate applied in rate-setting. An SVG plant has a lifetime approaching a century. SVG has zero-fuel-cost. The plant losses, plant power needs and even long-distance transmission losses are tied to capital costs of the displacing capacity rather than to escalating fuel costs.

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