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MORE ON DUAL PURPOSE SOLAR-ELECTRIC POWER PLANTS

F. F. HALL
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305, U.S.A.

ABSTRACT

Rationale for such plants is reviewed and plant elements are listed. Dual purpose solar-electric plants would generate both electricity and hydrogen gas for conversion to ammonia or methanol or direct use as a fuel of unsurpassed specific power and cleanliness. By-product oxygen would also be sold to owners of hydrogen age equipment. Evolved gasses at high pressure could be fired in compressorless gas turbines, boilerless steam-turbines or fuel-cell-inverter hydrogen-electric power drives of high thermal efficiency as well as in conventional internal combustion engines.

1. UTILITY OPERATIONS AND SITING

A dual purpose solar-electric plant (DUPSEP) as a minimum must be sized to handle the winter loads knowing that production will be increased by two hours during spring-fall and four hours during summer. The same demand versus percent of time used two years ago (1) is shown in Figure 1. Again the initial sites would be close to Yuma, Arizona where the sun shines close to 3945 of 8766 hours, or 45 percent of the time. Local time should be adjusted seasonally so that maximum energy demands occur while the sun is still well above the horizon. This requires a two-hour shift in winter, a one-hour shift in spring-fall and no shift in summer, since maximum loads occur between 12:00 noon and 6:00 PM. Siting parameters are shown in Table 1. Siting effects on plant operation are also shown in Table 1 where maximum power generation and minimum by-product production of H_2, O_2 is assumed to occur at Yuma, Arizona and MWHR sold is held to be 100 percent in all cases. The MWHR to production includes transmission losses between power plant generator output and utility customer bus-bar and rectifier/hydrolyzer losses in converting AC power to GH_2 and GO_2, A DUPSEP located near Boston, Massachusetts must be 240 percent larger than the ideal Yuma location, but will produce 205 percent more GH_2 and GO_2. This is of interest since fuel gas for home heating is a vital necessity in Minneapolis and Boston as compared to Yuma.

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2. ELEMENTS OF DUAL PURPOSE SOLAR-ELECTRIC POWER PLANT

These are listed hereunder. Solar collectors should be of the weightless, spherical balloon type (2), (3) having concentric tubular heat probes aimed at sun by tracking mounts positioned at the top of hollow conical concrete bases which will resist wind forces and can also serve as multi-level power houses. Heat collection should take place at 1089°K or 1506°K to permit use of modern, efficient steam turbines. Heat probe coolant should be a liquid metal alloy which will not freeze at ordinary nighttime temperatures and which can be very hot at low pressure. Collectors can be mounted in a triangular pattern with a separation distance of eight balloon diameters. Balloons will overhang the concrete bases which occupy 4 percent of collector field area. Land between bases can be used for any low-head-room purpose such as agriculture. Coolant pipes will have vacuum jackets for thermal insulation and to catch leaks. Liquid metal heat exchange to boiler feedwater and steam should take place in very compact, platefin type heat exchangers of stainless or super alloy to reduce cost. Steam turbines, generators, condensers, feedwater pumps and extraction heaters would be of the AIEEE/ASME preferred standard (4). Low temperature heat rejection would be to cooling tower water or water drawn from 17m below the surface of water reservoirs. Switchgear should be of the vacuum switch type to allow frequent on-off operation during partly cloudy weather. AC/DC rectifiers should be solid state to assure high efficiency. Hydrolyzers should be the back-pressured type with low-cost electrodes built into pressure tank walls (5) to allow dissociation to take place at gas transmission piping pressures. A back-up source of AC power is necessary to operate plant motors when the sun is hidden by clouds. Neon or hydrogen refrigerators could be used to liquefy oxygen and chill hydrogen offgassed from electrolyzers to enhance storage and transport. Figure 2 shows a typical heat balance. Figures 3 and 4 show subelements of the weightless solar energy collectors. Balloon buoyancy is obtained by cryogenic removal of oxygen from air at the power plant site so the natural buoyancy of nitrogen in air offsets the weight of moving collector parts.

The following is a list of DUPSEP elements:

1. Solar Energy Collectors with Sun Tracking Means and Heat Gathering Probes
2. Collector Coolant System Using NaK as Coolant
3. Coolant to Steam Side Heat Exchangers of the Platefin Type
4. Steam Turbine Generator Sets of the Preferred Standard Type
5. Condensers, Extraction Heaters and Boiler Feedwater Pumps
6. Condenser Cooling Water System; Cooling Towers or 17m Deep Lake Water
7. Vacuum Switches and Step Up/Down Transformers
8. Motor Control Center and Control Console
9. AC/DC Rectifiers and Hydrolyzers
10. H_2-O_2 Fuel Cell-Inverter Backup AC Power Source
11. Oxygen and Hydrogen Refrigerators
12. Chilled Hydrogen and LOX Storage
13. Thin-wall, Multi-level, Reinforced Concrete, Wind Resistant, Conical Base-Power Houses

3. EXTRACTION HEATING

In principle it is unnecessary to extract steam for boiler feedwater heating in a DUPSEP because liquid metal to water heat exchangers could be used and have a high "U" factor. However, the AIEEE/ASME Preferred Standard units are provided with multiple extraction points and extraction steam to water heaters which are mass-produced at low cost. The use of these Preferred Standard units offers the advantage of increased liquid metal to steam side temperature differences which will reduce cost of highest temperature heat exchangers. In addition the liquid metal temperature difference from hot side to cold side will be reduced which will enhance solar energy collection. Finally, the guaranteed thermal efficiencies of Preferred Standard turbine-generator sets are preserved. This is as shown in Figure 2.

4. ENERGY STORAGE

The low heat capacity of the primary DUPSEP eutectic sodium-potassium alloy coolant would require large quantities of expensive liquid metal stored in large thermally insulated pressure vessels to provide heat when sunshine is not available. Such an inventory would become a dominant cost factor. A far better way is to store energy in hydrogen gas by dissociation of water. Excess electrical power generated when the sun is shining can be used to produce hydrogen and oxygen using electrolytic cell-banks. Later the hydrogen and oxygen can be recombined in H_2-O_2 fuel cells and existing steam turbine-electric sets. The parameters of such arrangements are listed in Table 2 and a typical schematic is shown in Figure 5. To prove the point, it is assumed that both fuel cells and steam turbine generator sets are of moderate thermal efficiency while the combined hydrogen-electric power drives (6) offer excellent thermal efficiencies.

5. TEMPERATURE OF HEAT COLLECTION

Heat collection efficiency rises as the temperature of heat collection falls. This is true of weightless spherical balloon collectors which have been calculated at 672°K, 1089°K, 1506°K and 1922°K to have respective efficiencies of 74%, 70%, 64% and 54%. For a small DUPSEP the 672°K is adequate and is the limit for steel tubing heat probes. For a larger DUPSEP the 1089°K is adequate for plants having a single reheat and is the limit for low carbon austenitic stainless steel tubing heat probes. For a large DUPSEP the 1506°K is adequate for plants having double reheat and is the limit for 5% Fe Superalloys. Higher heat collection temperatures are attainable because weightless spherical balloon collectors have a concentration factor of 400 at all diameters of interest but there are no existing power systems which can make use of such high temperatures economically. A double reheat steam-electric plant adds 8% to thermal efficiency at a sacrifice of 6% of heat collection efficiency and an increased cost of NaK piping by a factor of 3 and of NaK steam-side heat exchangers of 8%. It is logical that initial DUPSEP plants will be designed to collect heat at 1089°K and hot parts will be of low carbon austenitic stainless steel irrespective of size since this represents an advanced power concept based on the technology of today.

6. SIZE OF WEIGHTLESS BALLOON COLLECTORS

The area of the collection field is independent of the size of the individual balloon collectors. The optimum balloon collector diameter is close to 61m or 200 feet. The liquid metal collector coolant piping will be a grid, and overall cost of piping will be much the same for a given size of collector field. In principle, there is no particular limit to balloon collector diameter, but costs rise slowly as diameter is increased above 61m. The rise in cost of individual collectors is more dramatic. As the diameter is doubled, unit costs rise by a factor of 4 to 5. Collector size parameters are contained in Table 3. Another factor that pertains is the service life expectancy of the balloon materials. Polyvinyl fluoride that is 0.01 cm. thick becomes embrittled after 12 to 14 years and can shatter if exposed to sharp raps or flapping. In the intended service neither sharp raps nor flapping should occur, but additional years of service cannot be predicted. The balloon portion of the collectors must be replaced once or twice during useful plant life. All of the above considerations militate toward selection of small diameters for the first DUPSEP plants. Later, as better film materials are developed, larger units may prove to be economical. For a 100 MWe DUPSEP plant using 61m diameter collectors, the loss of a single collector will reduce plant capacity by less than 1% and replacement of a clear hemisphere would cost about \$20/KWe.

7. STORAGE OF HYDROGEN & OXYGEN

GH_2 is very fluffy, occupying 5.54 steres at 1 atma pressure and 300^oK temperature. Hydrogen may be stored under pressure and/or in a chilled state to reduce bulk storage volume. In a small DUPSEP plant, storage of GH_2 and GO_2 at 68 atmas pressure should be adequate and further expense is not justified. Storage of GH_2 and GO_2 at greater pressures may be of interest for large DUPSEP plants. For each increase of pressure by a factor of 10, the power required to compress 1.008 g/s of GH_2 is 3.85 KW. The higher heating value of 1.008 g/s throughput of GH_2 is 143 KW, so the sacrifice of product is 2.7% per decade of increased pressure. The corollary sacrifice to compress GO_2 is 1.36%. For the chilling of GH_2 and the simultaneous conversion of GO_2 to LOX, the practical refrigerants are helium, hydrogen and neon. Of these, helium is inefficient, neon is very expensive, and the ready availability of GH_2 at a DUPSEP plant is a must. GH_2 is the natural selection. To chill GH_2 to 90^oK requires a sacrifice of 6.7% of the higher heating value of throughput of GH_2 and conversion of GO_2 to LOX requires a sacrifice of 7.3%. The combined sacrifice of 14% is not necessary at a DUPSEP plant, but could be of interest to hydrogen fueled aircraft or mobile craft on land, or at sea due to relative thinness of GH_2 and/or GO_2 storage tanks. An energy balance for simultaneous chilling of GH_2 and conversion of GO_2 to LOX at 90^oK is shown in Figure 6.

8. DUPSEP PLANT COSTS

Critical parameters and estimated costs of a 100 MWe DUPSEP plant are shown in Table 4 for seven assumed locations ranging from Yuma to Seattle. The total plant investment is for a firm capacity plant with rectifier/hydrolyzer units and gas cylinders used to stockpile dissociated GH_2 and GO_2 for subsequent firing in fuel cell/inverter units with exhaust steam piped to steam turbines driving alternators. Estimated costs of the extra equipment are $35/KWe for rectifiers, $50/KWe for hydrolyzers, $130/KWe for fuel cells and $40/KWe for inverters. The low cost for fuel cells is due to no need for a fuel processing section. For a solar-electric plant intended solely for peaking service, the cost of the extra equipment can be deleted which results in an investment that is 21% less than a DUPSEP plant, but does not solve the basic problem of generating power when the sun is not shining.

Critical parameters and estimated annual operating costs of a 100 MWe DUPSEP plant are shown in Table 5 for the same seven assumed locations. For the Yuma location, a 65% add-on investment penalty reflects the extraneous costs for transmitting and distributing the electrical power and fuel gas generated. This penalty rises slowly with increase of plant capacity in less sunnier climes because the electrical load is the same and only more fuel gas must be handled. Annual operating costs are taken as 11% of total system investment.

The determination of profitability of DUPSEP plants at this time is based on a differential escalation of 4% between the value of energy and everything else expressed in 1979 USD. The projected average 1979 US cost is $0.045/KWR and it is assumed that electrical output of a 100 MWe DUPSEP plant would be sold at this price. The projected average 1979 US cost is $0.018/KWHR for the heating value of fuel oil, but it is assumed that the GH_2 and GO_2 will be sold at nearly twice this price because these gasses can be recombined as shown in Fig. 5 to generate electricity at twice the thermal efficiency of plants firing petrofuels. The arbitrary value of $0.03/KWHR is selected as representative of the firing value of electrolytically pure GH_2 and GO_2. The profitable operation picture for a 100 MWe DUPSEP plant is shown in Table 6. A 100 MWe DUPSEP plant is small by recent standards, but availability should be very high and plants of this size can be operational within three years of a decision to proceed.

9. EPILOGUE

Similar plants to the DUPSEP can be built using geothermal heat, water currents or wind forces as free sources of energy. Since America is the largest user of energy obtained mainly by the depletion of non-replenishable fuels, it makes sense that the conversion of the world to a gaseous-hydrogen-fuel-based economy start here. If it is to be done well, it is important that we in America face up to the task and adopt a comprehensive energy program toward that end. As of now, America does not have such a policy. In the interest of helping obtain a national consensus on what we should do to assure ourselves and our successors complete success in meeting future energy requirements, I have appended a copy of "A Proposed Comprehensive Energy Program for America," which I first published in 1975 and which was also appended to References (1) and (5). It remains valid.

REFERENCES

1. Hall, F. F. 1977. Dual Purpose Solar-Electric Power Plants. 1st Miami Int. Conf. on Altern. Energ. Sources, Miami Beach, Fla.

2. Hall, F. F. 1977. Solar, Geothermal, Hydrogen & Hydraulic Power. Amer. Soc. Civ. Engr. Spring Conv., Dallas, Texas.

3. Hall, F. F. 1978. Weightless Solar Energy Collection. 1st Braz. Energ. Congr., Rio de Janeiro, Brazil.

4. The American Institute of Electrical and Electronic Engineers and the American Society of Mechanical Engineers. In particular, see page 9-84 Marks' Mechanical Engineers' Handbook, 6th Edition.

5. Hall, F. F. 1976. Hydrogen Production Plants Using Electrolytic Cells wtih Low Cost Electrodes Built into Pressure Tanks. 1st World Hydr. Energ. Conf., Miami Beach, Fla.

6. Hall, F. F. 1978. Hydrogen-Electric Power Drives. 1st Braz. Energ. Congr., Rio de Janeiro, Braz.

Table 1. Siting parameters and operations effects

Plant Location or Equal	Hours of Sunlight per Day			Hours of Sunlight per Year	% MWHR Annual Collection	% MWHR Annual Production	% MWHR to Produce Electrical Power	% MWHR Sales of Electrical Power	% MWHR to Produce GH_2 and GO_2	% MWHR Residual Heat Value in GH_2
	Winter	Spring-Fall	Summer							
Yuma	9	11	13	4,004	408	180	135	100	45	38
Las Vegas	8	10	12	3,640	423	186	136	100	50	42
Miami	7	9	11	3,276	441	194	138	100	56	48
New Orleans	6	8	10	2,912	463	204	140	100	64	55
Omaha	5	7	9	2,548	493	217	142	100	75	64
Boston	4	6	8	2,184	535	235	143	100	92	78
Seattle	3	5	7	1,820	602	265	145	100	120	102

NOTES

1. The difference between MWHR to produce electrical power and MWHR sales of electrical power reflects losses in H_2, O_2 fuel cells, rectifiers plus electrical transmission and distribution losses plus condensate and feedwater pumps, condenser water pumps, liquid metal pumps and cooling tower fans, if any.

2. Percent MWHR annual collection is based on high pressure high temperature steam-electric plants with single reheat and a thermal efficiency of 44%. See Figure 2.

3. A DUPSEP plant located in Boston will be 240% larger than the same plant located in Yuma, but will produce 205% more GH_2 and GO_2. See also Table 4.

4. Percent MWHR residual higher heating value in GH_2 is 85% reflecting the losses in rectifiers, hydrolyzers and in-plant electrical distribution.

Table 2. Hydrogen-electric power drive performance

Fuel Cell Efficiency Percent	Fuel Cell Output KW	Theoretical Exhaust Enthalpy w/g	Actual Steam Enthalpy w/g	Total Steam Flow Kg/Hr	Return Feedwater Flow Kg/Hr	Turbine Steam Flow Percent	Turbine Steam Rate g/WHr	Turbine Generator Output KW	Total Power Generated KW	Overall Thermal Efficiency Percent
0	0	4.41	0.917	54,151	42,891	100	4.276	12,664	12,664	25.5
10	4,966	3.97	0.917	48,748	37,488	90	4.426	11,014	15,980	32.2
20	9,931	3.53	0.917	43,345	32,085	80	4.575	9,474	19,405	39.1
30	14,897	3.09	0.917	37,943	26,683	70	4.832	7,852	22,749	45.8
40	19,862	2.65	0.917	32,540	21,280	60	5.131	6,342	26,204	52.8
50	24,828	2.20	0.917	27,014	15,754	50	5.644	4,786	29,614	59.6
60	29,794	1.76	0.917	21,611	10,351	40	6.842	3,159	32,953	66.4
70	34,759	1.32	0.917	16,209	4,949	30	9.878	1,641	36,400	73.3
80	39,725	0.88	0.917	11,260	0	20	INF	0	39,725	80.0
90	44,690	0.44	0.440	11,260	0	0	IMP	0	44,690	90.0
100	49,656	0.00	0.000	11,260	0	0	IMP	0	49,656	100.0

NOTES

1. Fuel cell output based on 1,260 Kg/Hr of GH_2 and 10,000 Kg/Hr of GO_2.
2. Theoretical exhaust enthalpy is based on residual heating value of GH_2÷11,260 Kg.
3. Actual steam enthalpy is based on 42 atma, 714°K throttle steam.
4. Total steam flow is the ratio of enthalpies times 11,260 Kg/Hr.
5. Return feedwater flow is total steam flow less 11,260 Kg/Hr.
6. Steam flow rises from 20% at no load to 100% at rated load.
7. Turbine-generator is taken as a 12,650 KW AIEEE-ASME Preferred Standard Unit with 600 PSIG, 825°F throttle steam, 1.5" Hg exhaust, 4 extractions, 348°F return feedwater and a steam rate of 10,375 BTU/KWHR.
8. Overall thermal efficiency is 100xtotal KW÷49,656 KW.

Table 3. Balloon collectors for a 100 MWe plant

Balloon Diameter Meters	Gross Solar KWt	Collector Efficiency at 1089°K,%	Input Power KWt	Output Power KWe	Number of Balloons for 100 MWe	Collector Unit Cost USD	Total Cost in 1000s of USD	Unit Cost USD/KWe	Unit Cost USD/KWt
30	621	71.6	445	196	510	28,887	14,732	147	65
61	2,482	71.3	1,770	779	128	114,059	14,600	146	64
91	5,584	70.5	3,937	1,732	58	269,002	15,602	155	68
122	9,928	70.2	6,969	3,066	33	510,005	16,830	166	73
152	15,513	69.7	10,813	4,758	21	846,097	17,768	178	78
183	22,340	69.4	15,504	6,822	15	1,294,703	19,421	190	84
213	30,405	69.1	21,010	9,244	11	1,863,398	20,497	202	89

NOTES

1. Gross solar KWt is based on 0.85 KW/m^2 of transverse collector area which includes a 10% loss to account for haze at dawn and dusk
2. Collector efficiency falls off slowly with increased diameter due to need for thicker reinforcement roping to restrain internal pressure of 1.012 atma used to offset null point pressure at 160 Km/Hr wind velocity
3. Output power is based on 44% of input power. See Figure 2.
4. Estimated costs are based on 1979 USD.
5. Estimated costs include the conical base-power houses.
6. Inasmuch as solar collectors convert sunlight into heat, the unit cost per thermal KW is preferred as being more straightforward.

Table 4. Estimated cost of a 100 MW DUPSEP plant

Assumed Plant Location	Yuma	Las Vegas	Miami	New Orleans	Omaha	Boston	Seattle
Rated Plant Capacity, MWe	100	114	132	156	190	240	325
Total Plant Capacity, MWe	105	120	138	164	200	252	341
Plant Collection, MWt	239	273	314	373	455	573	775
Estimated Capital Cost in Millions of 1979 USD:							
Collectors @$65/KWt	15.5	17.7	20.4	24.2	29.6	37.2	50.4
NaK Coolant System @$35/KWt	8.4	9.6	11.0	13.1	15.9	20.1	27.1
NaK to Steam Side Heaters @$45/KWe	4.7	5.4	6.2	7.4	9.0	11.3	15.3
T-G-C, SWGR, Cooling Water @$155/KWe	16.3	18.6	21.4	25.4	31.0	39.1	52.9
Rectifiers, Electrolyzers @$85/KWe (50% Cap.)	4.5	5.1	5.9	7.0	8.5	10.7	14.5
Fuel Cells, Inverters @$170/KWe (50% Cap.)	8.9	10.2	11.7	13.9	17.0	21.4	29.0
Land and Other Costs	5.9	6.7	7.7	9.1	11.1	14.0	18.9
Replacement Balloon Material @$20/KWt	4.8	5.5	6.3	7.5	9.1	11.5	15.5
Total Plant Investment	69.0	78.8	90.6	107.6	131.2	165.3	223.6

NOTES

1. In a DUPSEP plant the cost of solar energy collectors also includes the cost of the power houses.
2. Since DUPSEP plants are modular, added capacity above firm capacity is reckoned at 5% of firm capacity.
3. The unit plant cost in USD/KW is 10 times the numerical plant value in millions of 1979 USD.
4. Cost estimates are based on 1979 USD.
5. Replacement balloon materials assumes one replacement of transparent hemispheres after 12-14 years.

Table 5. Annual operation of a 100 MW DUPSEP plant

Assumed Plant Location	Yuma	Las Vegas	Miami	New Orleans	Omaha	Boston	Seattle
Energy Quantities in millions of KW-HR:							
Annual Collection of Heat	898	930	970	1,019	1,085	1,177	1,324
To Electrical Power	396	409	427	449	477	517	583
Electrical Sales	220	220	220	220	220	220	220
To Excess GH_2, GO_2	99	110	123	141	165	205	264
Fuel Value of Excess GH_2	84	94	106	120	141	172	224
Estimated Costs in Millions of 1979 USD:							
Total Plant Investment	69.0	78.8	90.6	107.6	131.2	165.3	223.6
Add for Transmission, Distribution	44.9	46.9	49.2	52.1	55.6	60.1	66.4
Total System Investment	113.9	125.7	139.8	159.7	186.8	225.4	290.0
Annual Production Costs @11%	12.5	13.8	15.4	17.6	20.5	24.8	31.9

<u>COSTS</u>

1. Fuel value of GH_2, GO_2 is based on 85% combined efficiency of inverter and hydrolyzers.
2. See Table 4 for detail of total plant investment.
3. Estimated investment for transmission and distribution is based on 65% of total plant investment for Yuma and increased by the 1/3 power for less sunny climes.
4. Annual production costs for a DUPSEP plant are taken for 25 years with interest at 9%, linear payback at 4%, operation and maintenance at 2.0% and customer accounting and administration at 0.5% which is 9/2+4+2+0.5 = 11%.

Table 6. Profitable operation of a 100 MW DUPSEP plant

Location of DUPSEP Plant	Annual Production Cost in Millions of 1979 USD	Projected Annual Sales of a 100 MW DUPSEP Plant in millions of 1979 USD (present worth)							
		1983	1984	1985	1986	1987	1988	1989	1990
Yuma (1983)	12.5	14.5	15.1	15.7	16.3	17.0	17.7	18.4	19.1
Las Vegas (1984)	13.8	14.9	15.5	16.1	16.7	17.4	18.1	18.8	19.6
Miami (1986)	15.4	15.3	15.9	16.6	17.2	17.9	18.6	19.4	20.1
New Orleans (1988)	17.6	15.8	16.4	17.1	17.8	18.5	19.2	20.0	20.8
Omaha (1991)	20.5	16.5	17.2	17.9	18.6	19.3	20.1	20.9	21.8
Boston (1995)	24.8	17.6	18.3	19.1	19.8	20.6	21.4	22.3	23.2
Seattle (2000)	31.9	19.4	20.2	21.0	21.9	22.7	23.7	24.6	25.6

NOTES

1. Details of annual production costs are shown in Table 5.
2. 1983 is selected as the first year of revenue because it is unlikely a 100 MW DUPSEP plant could be operational before late 1982.
3. It is assumed that the cost of fossil and nuclear fuels and the cost of power and fuel gas generally will escalate at 12% per year through 1990 and the cost of everything else will escalate at 8%, so the 1983 revenues are multiplied by 1.04 to the nth power in years to reflect present worth of future revenues.
4. The years in parentheses after DUPSEP locations are the estimated first year of profitable operation defined as minimum excess of revenue to be 9%.

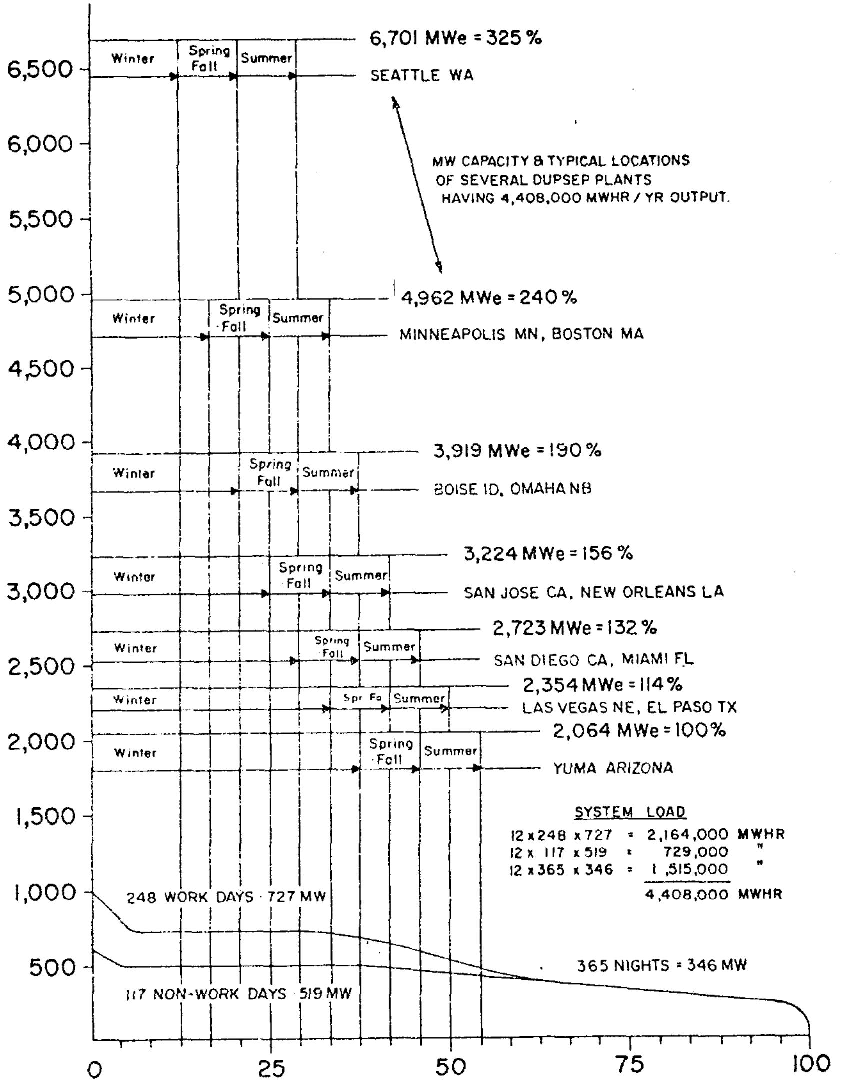
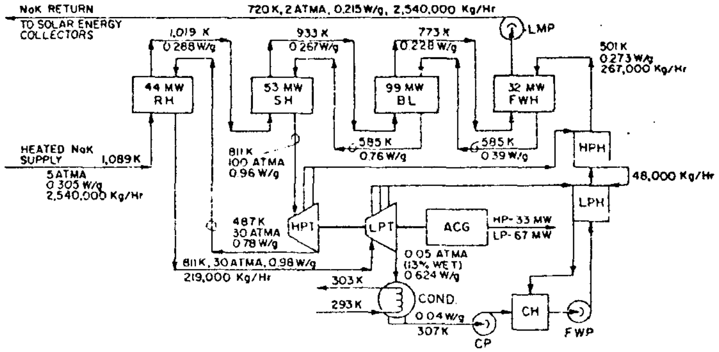


FIG. 1 MW DEMAND and MWe CAPACITY VS. % of TIME



NOTES

1. RH = REHEATER, SH = SUPERHEATER, BL = BOILER, FWH = FEEDWATER HEATER LMP = LIQUID METAL PUMP, HPT = HIGH PRESSURE TURBINE CASING, LPT = LOW PRESSURE TURBINE CASING, ACG = ALTERNATING CURRENT GENERATOR, HPH = HIGH PRESSURE EXTRACTION HEATERS, LPH = LOW PRESSURE EXTRACTION HEATERS, FWP = FEEDWATER PUMP, CH = CONDENSATE HEATER, CP = CONDENSATE PUMP, COND = CONDENSER

2. THERMAL EFFICIENCY = 100 x 100MW / (44MW + 53MW + 99MW + 32MW) = 44 %

3. THE TURBINE-GENERATOR IS A 100MW AIEEE, ASME PREFERRED STANDARD UNIT WITH 1450 PSIG, 1000°F INITIAL STEAM, 5 EXTRACTIONS, 442°F FEEDWATER & A HEAT RATE OF 8,150 BTU/KWHR WHEN CONDENSER BACK PRESSURE = 1.5" Hg

FIG 2
TYPICAL SOLAR PLANT STEAM-ELECTRIC HEAT BALANCE

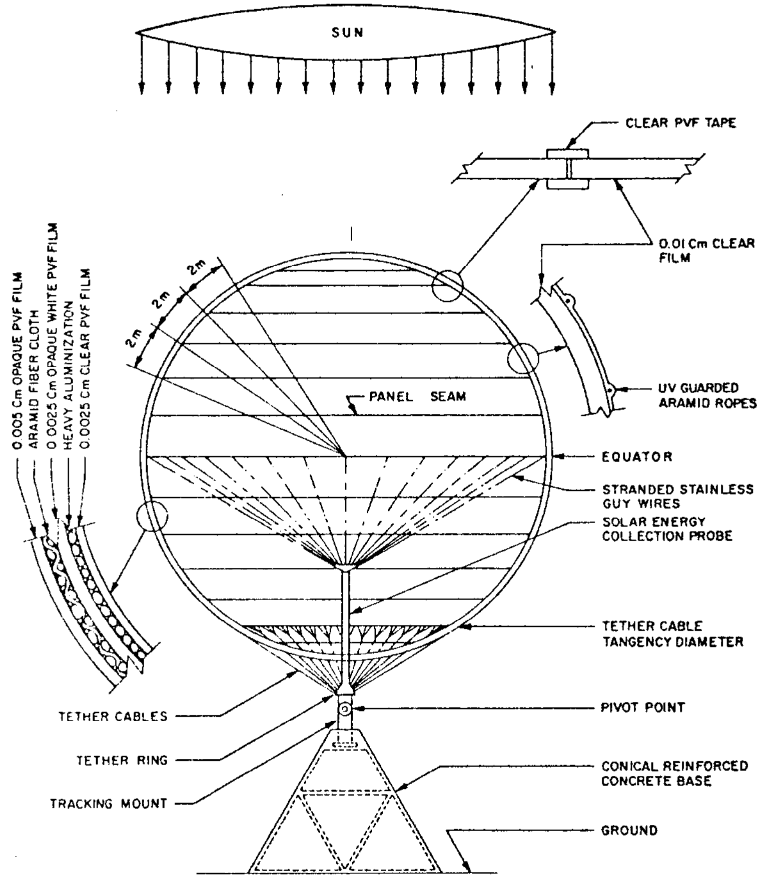


FIGURE 3

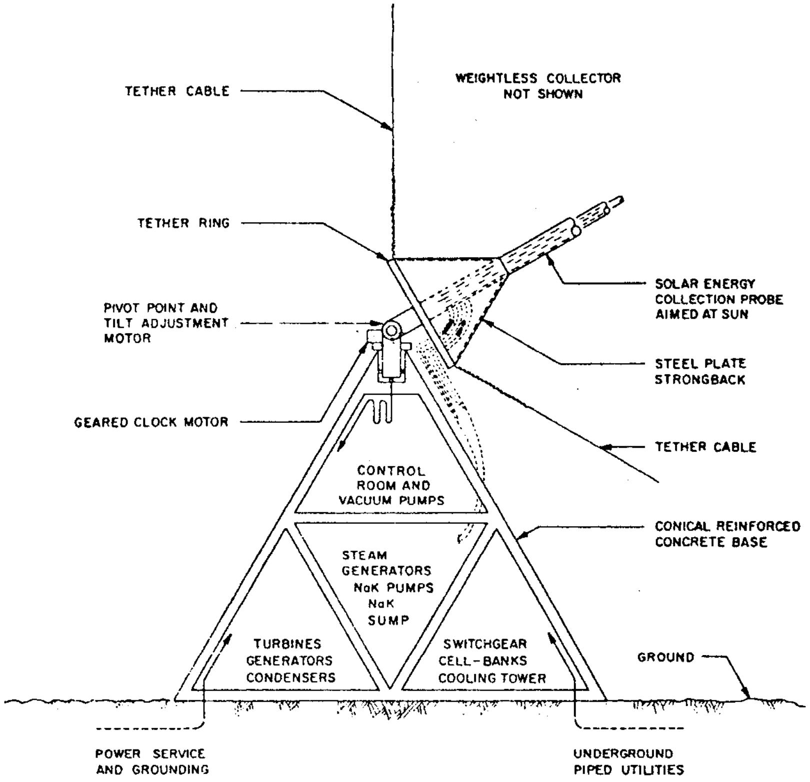
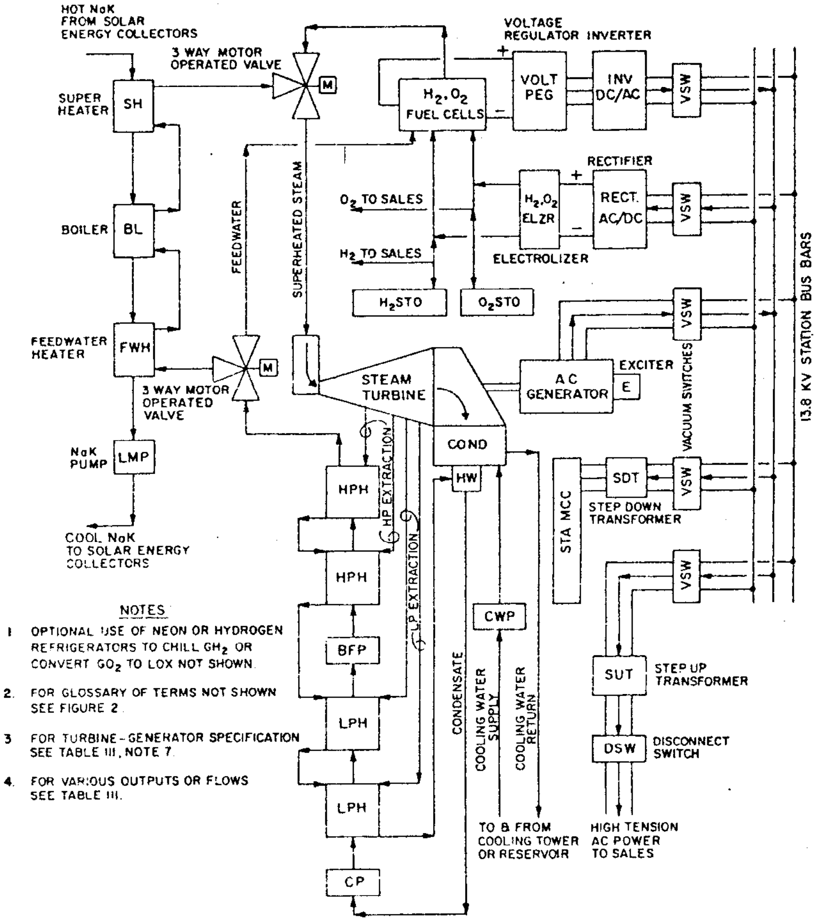


FIGURE 4



NOTES

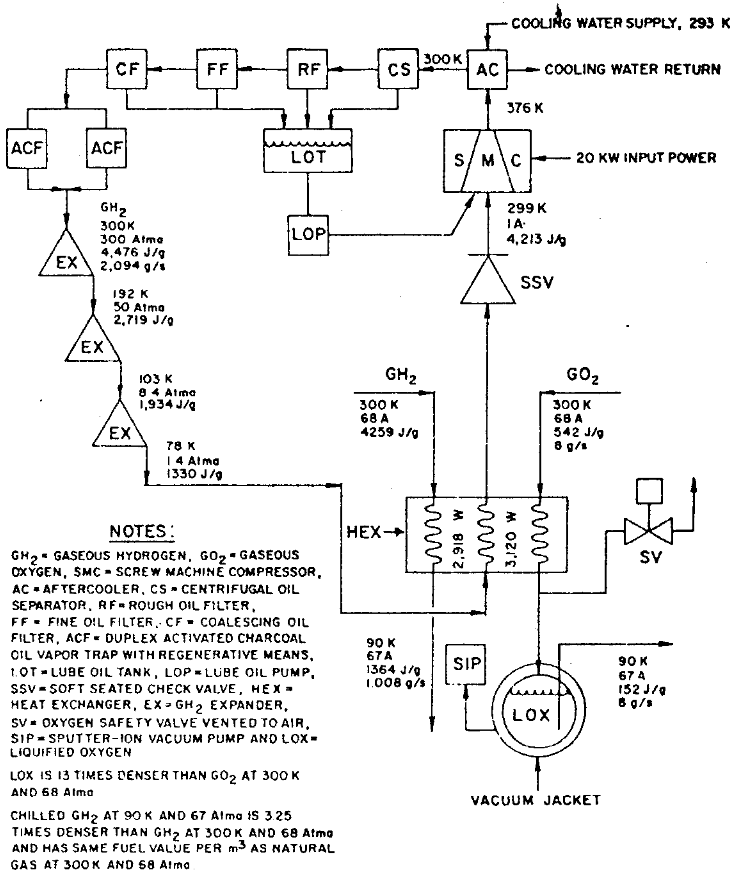
1 OPTIONAL USE OF NEON OR HYDROGEN REFRIGERATORS TO CHILL GH_2 OR CONVERT GO_2 TO LOX NOT SHOWN.

2. FOR GLOSSARY OF TERMS NOT SHOWN SEE FIGURE 2.

3 FOR TURBINE-GENERATOR SPECIFICATION SEE TABLE III, NOTE 7.

4. FOR VARIOUS OUTPUTS OR FLOWS SEE TABLE III.

FIG. 5 HYDROGEN POWER DRIVES FOR AC POWER GENERATION



NOTES:

1. GH_2 = GASEOUS HYDROGEN, GO_2 = GASEOUS OXYGEN, SMC = SCREW MACHINE COMPRESSOR, AC = AFTERCOOLER, CS = CENTRIFUGAL OIL SEPARATOR, RF = ROUGH OIL FILTER, FF = FINE OIL FILTER, CF = COALESCING OIL FILTER, ACF = DUPLEX ACTIVATED CHARCOAL OIL VAPOR TRAP WITH REGENERATIVE MEANS, LOT = LUBE OIL TANK, LOP = LUBE OIL PUMP, SSV = SOFT SEATED CHECK VALVE, HEX = HEAT EXCHANGER, EX = GH_2 EXPANDER, SV = OXYGEN SAFETY VALVE VENTED TO AIR, SIP = SPUTTER-ION VACUUM PUMP AND LOX = LIQUIFIED OXYGEN

2 LOX IS 13 TIMES DENSER THAN GO_2 AT 300 K AND 68 Atma

3. CHILLED GH_2 AT 90 K AND 67 Atma IS 3.25 TIMES DENSER THAN GH_2 AT 300 K AND 68 Atma AND HAS SAME FUEL VALUE PER m^3 AS NATURAL GAS AT 300 K AND 68 Atma

FIG. 6 HYDROGEN COLD GAS REFRIGERATOR SCHEMATIC

APPENDIX

A PROPOSED COMPREHENSIVE ENERGY PROGRAM FOR AMERICA

1. Preamble: America, like many other nations, is faced with an energy crisis as of 1975 A.D. Yesterday we generated growing amounts of electrical power using cheap, abundant, fossil fuels. Today we generate immense amounts of power using expensive fossil fuels and fissionable reactor fuels which are source limited. If we buy contemporary fuels we will become impoverished. If we do not, American culture will decline unless we turn to a non-fossil-non-fissionable fuel. Fortunately, such a fuel exists in abundance and is readily obtainable. Better yet it can be used, with minor changes, in existing equipment. Conservation of energy makes good sense above and beyond contemporary value of dollars. Most heat sources in common use today are source limited. These include natural gas, oil, coal, and fissionable nuclear fuels. Other potential fuels such as shale oil, burnable trash, wood, methane from garbage and wood alcohol are also source limited. Fission reactors including regenerative fueled breeder reactors may never be economical and will always be dangerous. Fusion reactors might solve our problems but when this will occur is unknown in terms of decades to centuries or never. Maximum use should be made of free power available from even remote waterfalls, known channels of strong winds, known channels of high oceanic tides or currents and optimum areas of strong insolation. Such programs would (1) stretch out world reserves of fossil fuels; (2) make fissionable fuels unnecessary; (3) solve our immediate energy problems for millenia, and; (4) permit diversion of technical talent toward solution, if this is possible to man, of how to obtain controlled and beneficial power from fusing atoms. Any programs to arbitrarily curtail use of energy by individuals or families should be undertaken only as a last resort and lifted at earliest opportunity. In best interest of people everywhere, low cost energy should be readily available in ever increasing amounts.

2. Fusion Reactors: Fusion reactors as opposed to fission reactors have marvelous potential for man in his quest for ever greater amounts of power. Nuclear ashes from such plants are short-lived and nowhere near as nasty as those from fission reactor plants. In-plant accidents would be equivalent, damagewise, to explosions of boiler drums or structural failures of small dams. Unlimited power would be available through fusion reactor plants and fuel is totally plentiful. We should intensify our R and D efforts to solve this extremely vexing technical problem. If we succeed, we will have no energy source shortage and even can realistically envision practical space travel not only to other solar planets but to other stars. That we may not succeed should not deter our efforts. At least we would have tried. Inability to predict when we will succeed, if ever, to develop fusion reactor plants makes it vital that we develop alternate power systems that will allow us to exist here on earth as we want to.

3. Kelp Technology: About three-quarters of the earth surface is ocean. Remaining one-quarter consists of six continents, one subcontinent, two dozen large island and innumerable smaller islands, cays and reefs. Extent of littoral in sufficiently warm areas is enormous. If buoy-supported lattices are placed in shallow coastal waters, seeded kelp will grow and cling to these horizontal frames. Where there is kelp, there can be fish, seals and birds. If man, everywhere, places such frames in shallow oceanic waters, even at great distances from shores then a plethora of balanced (plant and animal) ecological subsystems will be result. Kelp can be converted into edible food in part as is true of all genera of animal life. Artificially initiated kelp beds can vanquish hunger, an ancient enemy of mankind. Kelp is buoyed toward surface by rounded pockets which contain methane. Methane can be used to fuel most internal combustion engines and fossil-fuel fired heaters. Vigorous prosecution of kelp technology might ultimately solve our gastronomic and energy needs. In the meantime we need a readily obtainable, non-fossil-non-fissionable fuel which, with minor adjustments to carburetors or burners, can be used in existing equipment. It must, for economy, be obtained using free fuel, exist in abundance, be readily transportable and be about as safe to use as natural gas, methane or gasoline. Obtaining such a fuel should require very little in way of research and development so that it can be brought to market within a decade. Fortunately, such a fuel exists. It is hydrogen.

4. Hydrogen Gas as an Answer: Hydrogen gas burns to water in air. It is as clean as any fuel can be. Its energy content per pound is three times that of petrofuels and four times greater than best grades of coal. While very light, it can be stored under high pressures. Except for rockets, where liquefaction of hydrogen and oxygen is justified, hydrogen as a fuel should be delivered to users as a gas. Hydrogen can be burned in any commercially available furnace, gas-fired heater, gas-fired stove, or internal-combustion engine with a minimum of alteration to carburetors. Hydrogen is extremely plentiful. There are two atoms of hydrogen in almost all molecules of water on this planet. To obtain pure hydrogen, one can liquefy air at great expense and decant 0.5 parts per million of liquid hydrogen. To obtain pure hydrogen at normal temperatures, one can disassociate acidic water using electrolytic cells and this takes exactly as much energy as will be regained when envolved hydrogen is burned later. It follows that hydrogen gas fuel plants must use free fuel to generate power needed for production of gas on an ecomomical basis. Fortunately, free energy sources exist, upon reasonable investment, for energy conversion equipment. These include energy available from falling water, rapidly flowing water, geothermal heat, blowing winds, ocean currents and insolation. Most of these are not available on a full-time basis. River flows vary widely between wet and dry seasons. Winds can blow from any direction with widely varying force. Sunshine is at best a less than 50% proposition. Another even more vague possiblity is use of remote area agricultural chaff or wood alcohol as fuel for generating power to produce hydrogen gas. Beauty of these answers is that any part-time, free-fuel process

for hydrogen gas production produces a clean fuel which can be used any time later, anywhere, and for any existent fuel burning purpose except riddance of burnable trash. It is more efficient and less expensive to transmit power as gaseous fuel through underground pipes than as electricity using overhead transmission lines. Widespread use of hydrogen-gas-producing plants eliminates any need for storing large blocs of electrical power which would be very expensive and may be impractical. In many cases it might be economical to fire hydrogen gas in existing steam electric plant furnaces, particularly for shaving peak loads of public power utilities and large manufacturing plants. Hydrogen plant generators can be unitized and have no electrical switchgear to lower investment. An unusual feature of such plants is that generator rotors can rotate at any speed with wide ranges of output voltage and current. As long as there is current, hydrogen gas will evolve at cathodes. This is decidedly not true of conventional plants which generate electrical power and must operate at synchronous speeds or not at all. Hydrogen can be chilled using neon compression to insure adequate throughput through existing pipelines. Hydrogen plants should be fully automated with routine annual visits for maintenance. Hydrogen would reach market by pipelines or in barges or tankers and should be contaminated to (1) have an odor for fast leak detection, (2) have a visible flame for checking burner performance and (3) not weaken steel pipes or tanks by the embrittlement process.

5. <u>Where can Government Help?</u> Most of costs of conversion to a hydrogen gas fuel-based economy can and should be borne by utility companies and private oil companies. Costs of new hydrogen plants will be easily offset by not building fission plants and not importing foreign petrofuels. Car manufacturers can amortize costs of design changes over five years and existing vehicles can continue to be used by changing carburetors. Certain contemporary uses of fossil fuels, under present circumstances, are now against good public policy. These include heating swimming pools using natural gas-fired heaters, heating buildings, cooking food or drying clothing using electricity, air conditioning of buildings and vehicles using motor-driven refrigerant compressors, electric battery-driven cars and use of oil mixed into gasoline in 2-cycle internal combustion engines to drive motorcycles, power mowers and outboard motorboats. Public laws should be initiated to ban or discourage such use to encourage their replacement with solar heating systems, hydrogen or methane gas-fired heaters, engine exhaust waste-heat-recovery-fired absorption-type air conditioning units and hydrogen or methane gas-fired, 4-cycle internal combustion drives for small mobile power plants. Suggested replacements are all more efficient, quieter and free of noxious emissions. A ten-year transition period is suggested as co-equal with average life expectancy of such equipment.

6. <u>Fission Reactors</u>: America has spent enormous sums on various atomic programs relating to obtaining fissionable material and its use for peace as well as war. We have produced reliable A-bombs and can use them to trigger H-bombs. We have produced reliable power systems for U-boats armed with H-bomb-laden rockets which preserve such international

peace as exists on this planet. Through MIRV we can potentially deliver more H-bombs than there are rockets to carry them. We cancelled a program to power planes using reactor plants as unnecessary, very expensive, and downright dangerous. We have built numerous fission reactor plants for producing electric power but have not developed plans for safe disposal of nuclear ashes developed by such plants. These plants cannot be justified because they are very expensive, nuclear fuel is rarer than coal, oil or gas, they operate about 67% of time as opposed to 88% on-line record of conventional power plants and their spent fuel elements are a terrible threat should these escape containment. Breeder reactors make more sense but not enough sense. While nuclear fuel could be regenerated again and again, cost per plant is much greater, on-line time will be no better and chances of accidental escape of nuclear wastes are increased. Fission reactors should be shut down systematically at earliest possible date as other, safer and more practical methods of power generation come into use.

7. Implications: Best bet for man, in absence of fusion reactor power plants, to progress with ever increasing amounts of power is to make hydrogen gas which can be used anywhere, any time for any productive, clean, fuel burning purpose. The conversion of America to a hydrogen-fuel-based economy will be complete when many large fossil-fuel-fired electrical generating plants have been replaced by fuel cell plants and all fissionable fueled nonmilitary reactors have been mothballed. Ultimately people or groups requiring power will obtain hydrogen (or methane produced from kelp) through underground piping or from storage tanks and will own their own low capacity, mass-produced, low cost, low voltage ac or dc generators driven by gas-fired engines. Whatever applies in America will also apply in any other nation on earth, including OPEC countries. Until kelp technology is fully developed, fossil fuels will be used for production of plastics which all of us find to be of utmost convenience in so many ways. Humanity will find its Hydrogen Age to be a very exciting time.