An Integrated Renewable Energy/ Fuel Cell Power Generation System

- a preliminary study -

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- A New Way of Storing Electricity
- System Configuration
- Performance of the Existing PV System
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- Hydrogen Production and Storage
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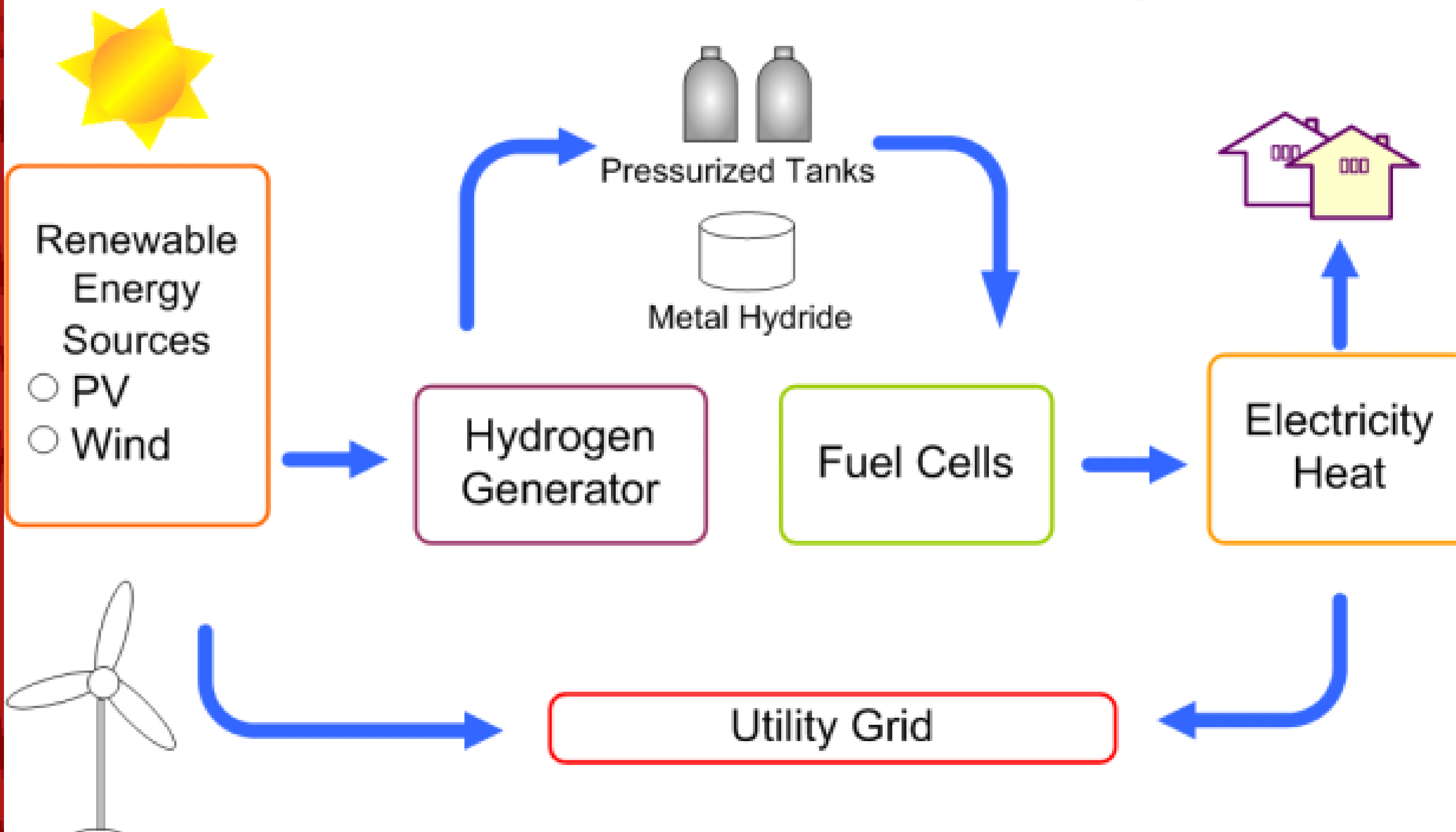
Comparison of Different Electricity Storage Technologies

MODE	***ENERGY FORM***	***ADVANTAGE***	***DISADVANTAGE***
Pumped Hydro	Potential	Matured technology, quick response	Location
Compressed Air	Internal	Matured technology	Location, need extra auxiliary power
Superconductor	Magnetic	Efficiency	Technology under research
Battery	Chemical	No limitation on location, quick response	Cost, life, weight, safety
Regenerative Fuel Cells	Chemical	Efficiency, environmentally friendly	Developing technology, cost, capacity limitation

An Integrated Renewable Energy/ Fuel Cell Power Generation System



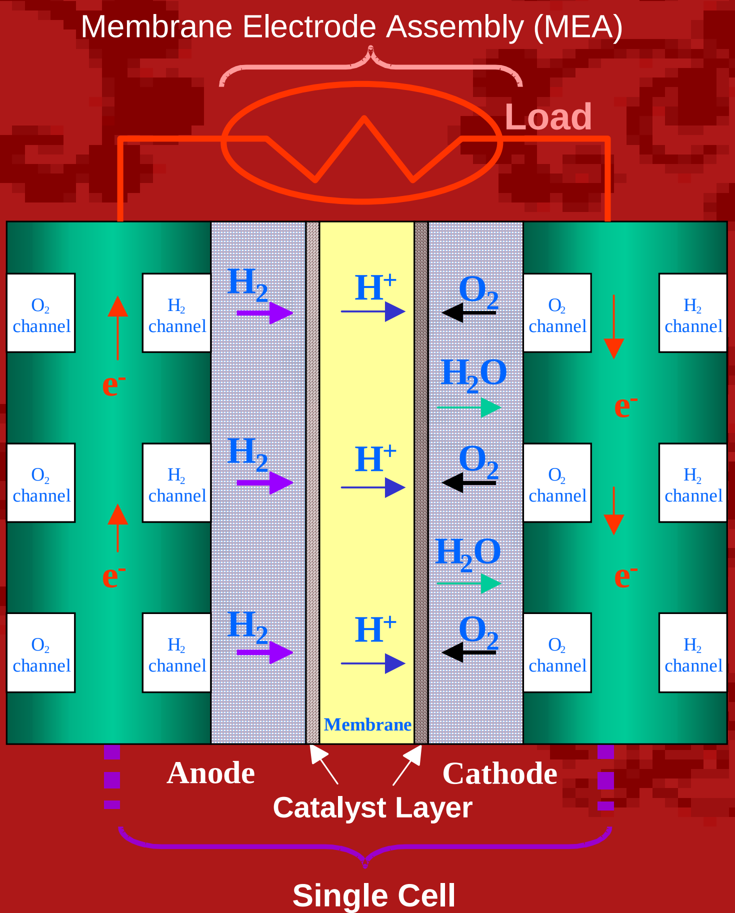
What Is a Fuel Cell ?

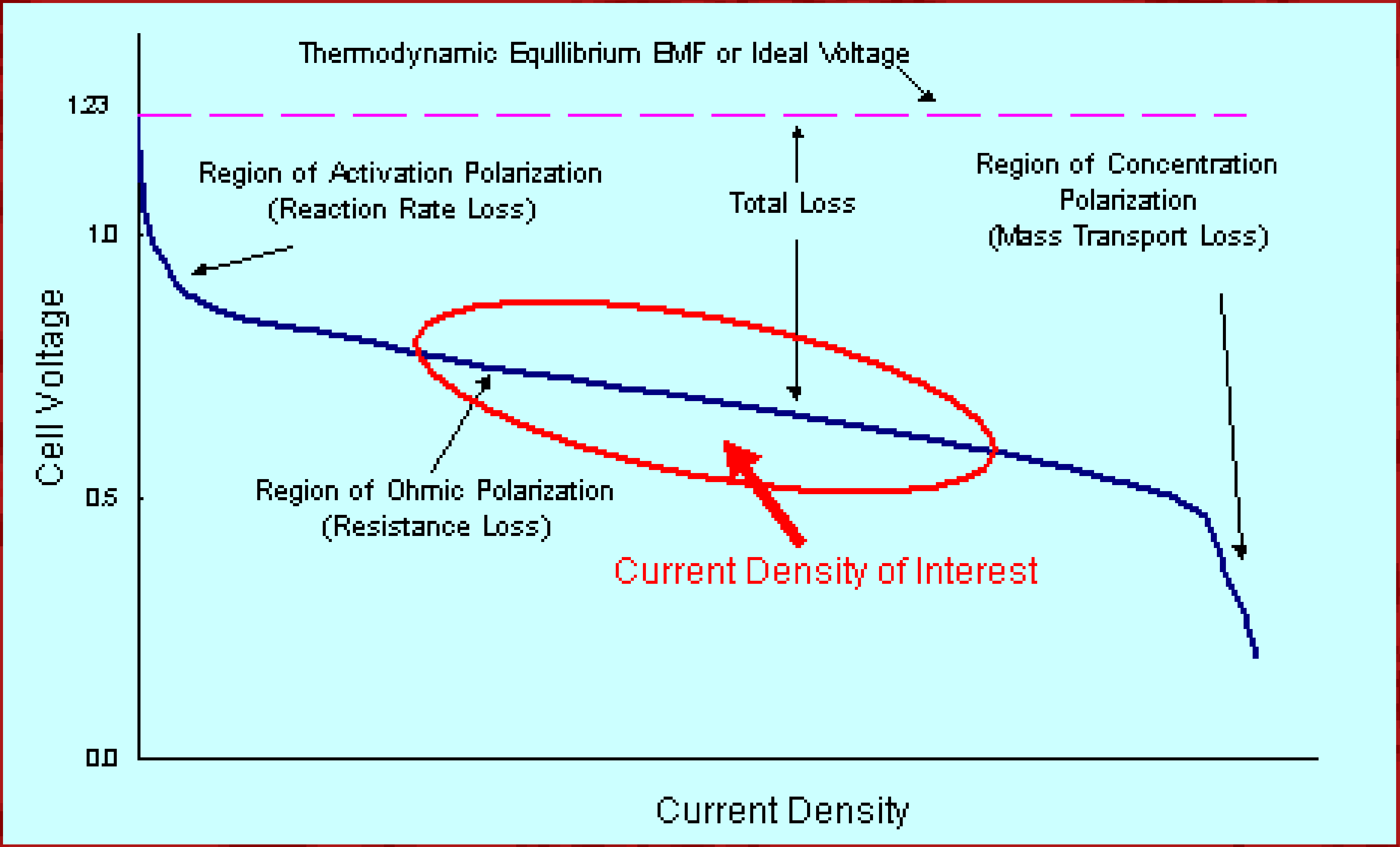
Combining hydrogen and oxygen to generate electricity and heat

Basic Reactions

	Anode	Cathode
	$H_2 \rightarrow 2H^+ + 2e^-$	$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

- A device that converts the chemical energy of fuels directly into electricity and heat via electrochemical reactions
- Similar to a primary battery except that the source of energy is continuously fed from outside
- Individual fuel cells are assembled into modules (stacks) to provide a practical voltage and power output




Thermodynamic Equilibrium EMF or Ideal Voltage
1.23
1.0
0.5
0.0
Cell Voltage
Region of Activation Polarization
(Reaction Rate Loss)
Total Loss
Region of Concentration
Polarization
(Mass Transport Loss)
Region of Ohmic Polarization
(Resistance Loss)
Current Density of Interest
Current Density

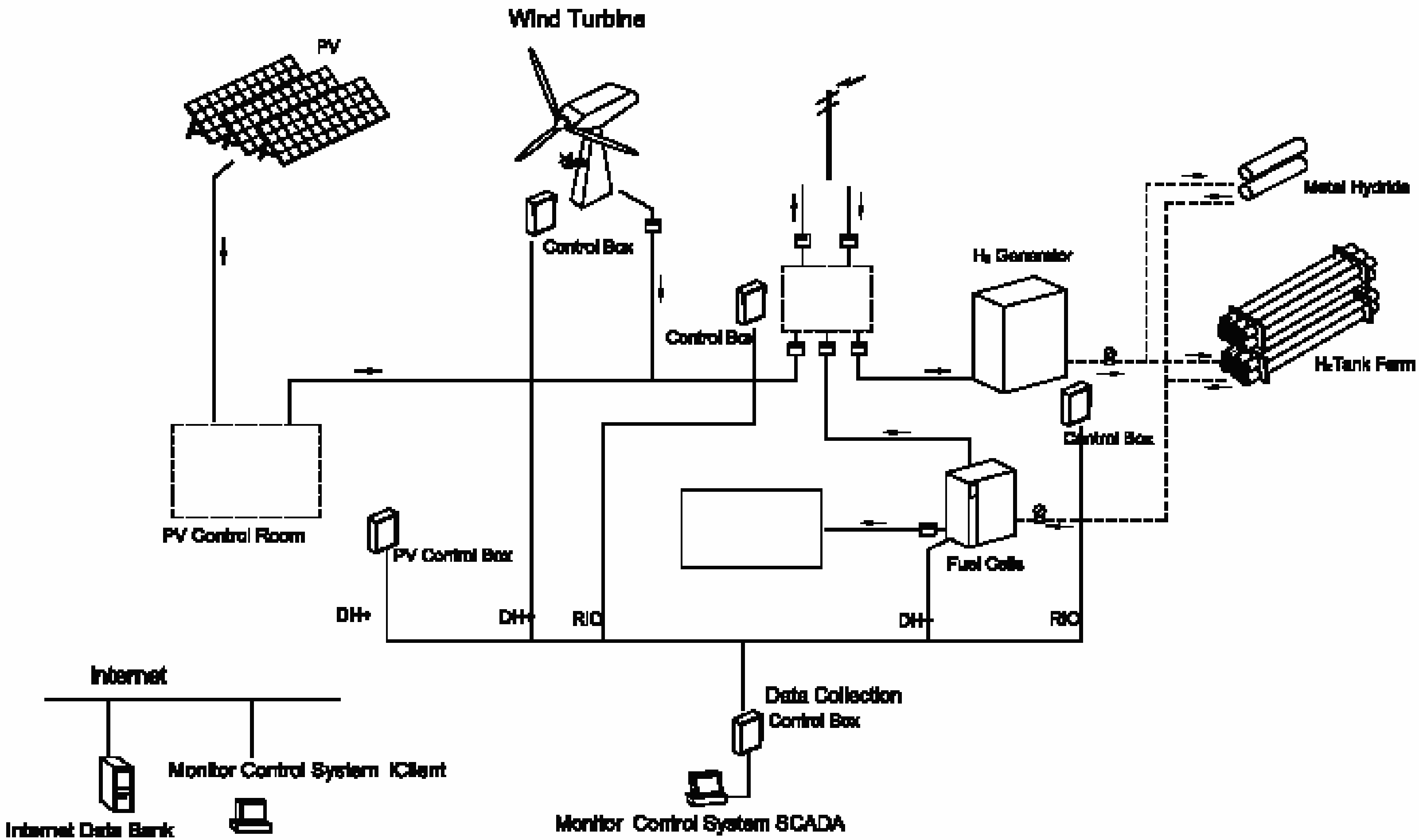
Reactant Gas Flow Rates for Fuel Cells Generating 1 kW Electricity

	Hydrogen				Oxygen		Air	
Voltage per cell (volts)	1.0 St (slpm)#	Fuel * Economy (%)	1.2 St (slpm) #	Fuel * Economy (%)	1.0 St (slpm) #	2.0 St (slpm) #	1.0 St (slpm) #	2.0 St (slpm) #
1.0	6.964	79.75	8.356	66.47	3.482	6.694	16.580	33.161
0.9	7.737	71.78	9.285	59.82	3.869	7.737	18.423	36.846
0.8	8.705	63.80	10.446	53.17	4.352	8.705	20.725	41.451
0.7	9.948	55.83	11.938	46.52	4.974	9.948	23.686	47.372
0.6	11.606	47.85	13.927	39.88	5.803	11.606	27.633	55.268
0.5	13.927	39.88	16.713	33.23	6.964	13.927	33.160	66.321
0.4	17.409	31.90	20.891	26.59	8.705	17.409	41.451	82.901
0.3	23.212	23.93	27.855	19.94	11.606	23.212	55.268	110.535

* based on LHV of hydrogen (57.7979 kcal/mole)

\# standard liters per minutes (0 °C and 1 atm)

SYSTEM CONFIGURATION



Major Components

1 Renewable Energy Sources

① photovoltaic power generation

② wind power generation

2 Hydrogen Production and Storage

① PEM vs. alkaline electrolysis

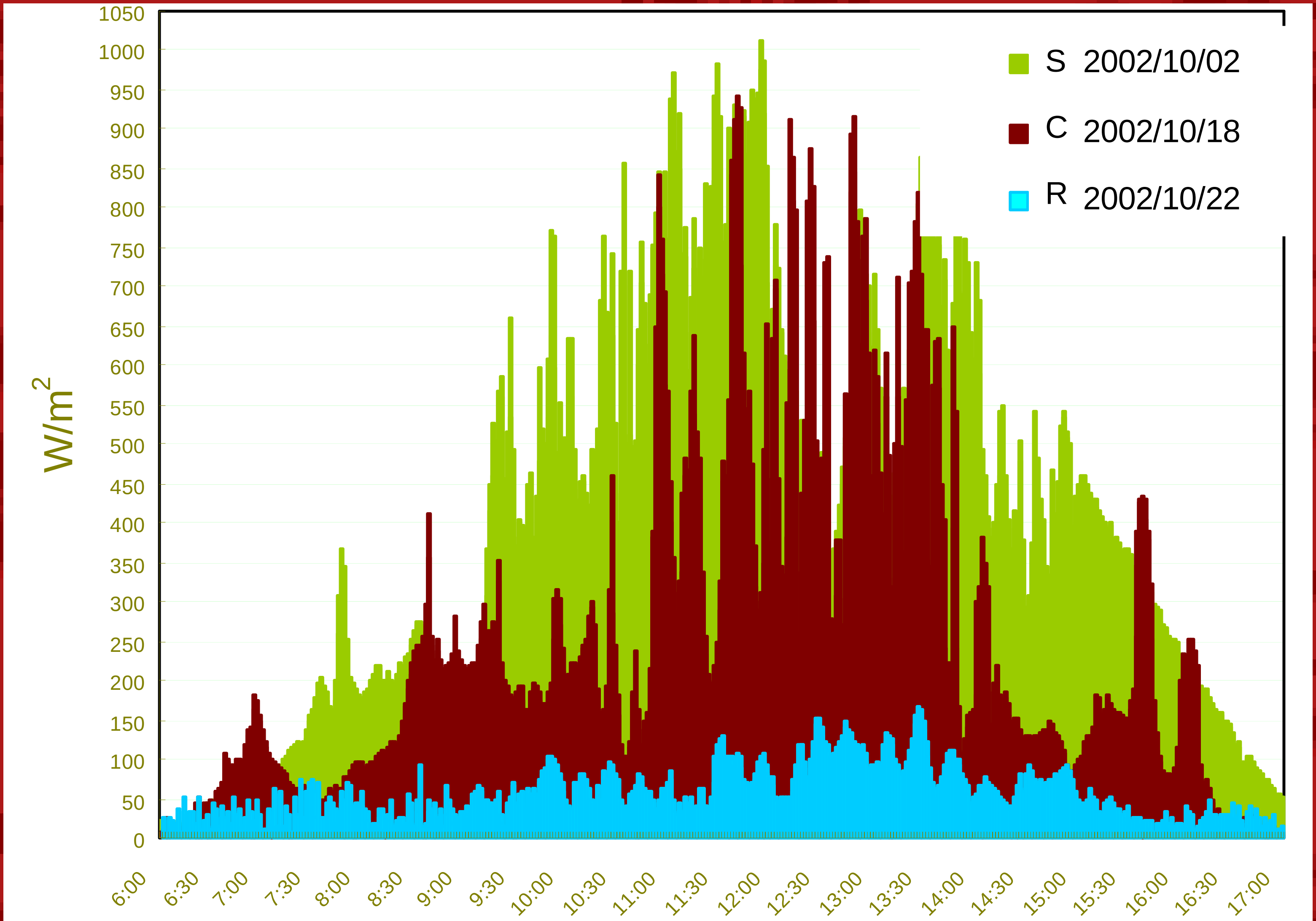
② pressurized tanks vs. metal hydride

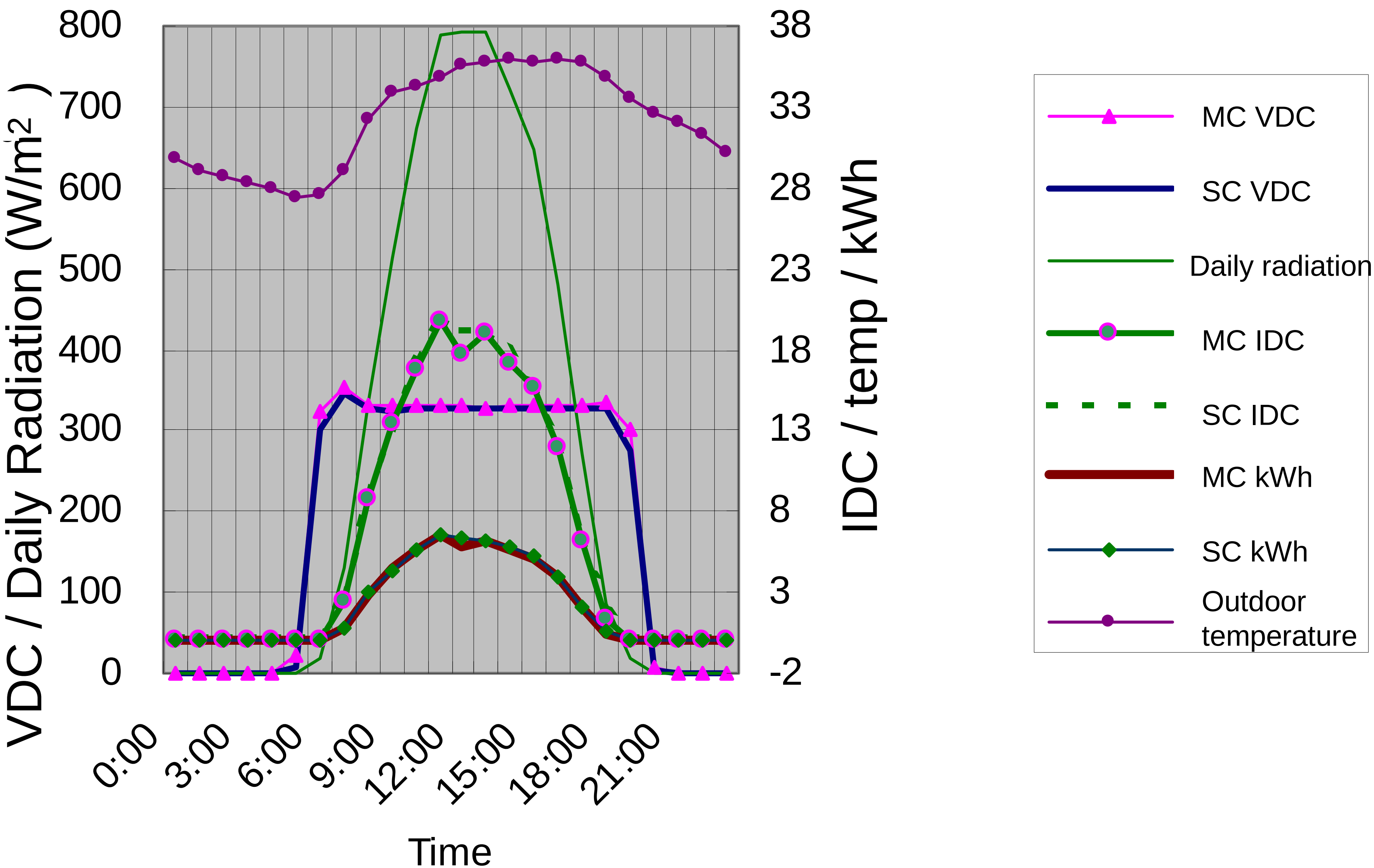
3 Fuel Cells Power Generation System

4 Load Display

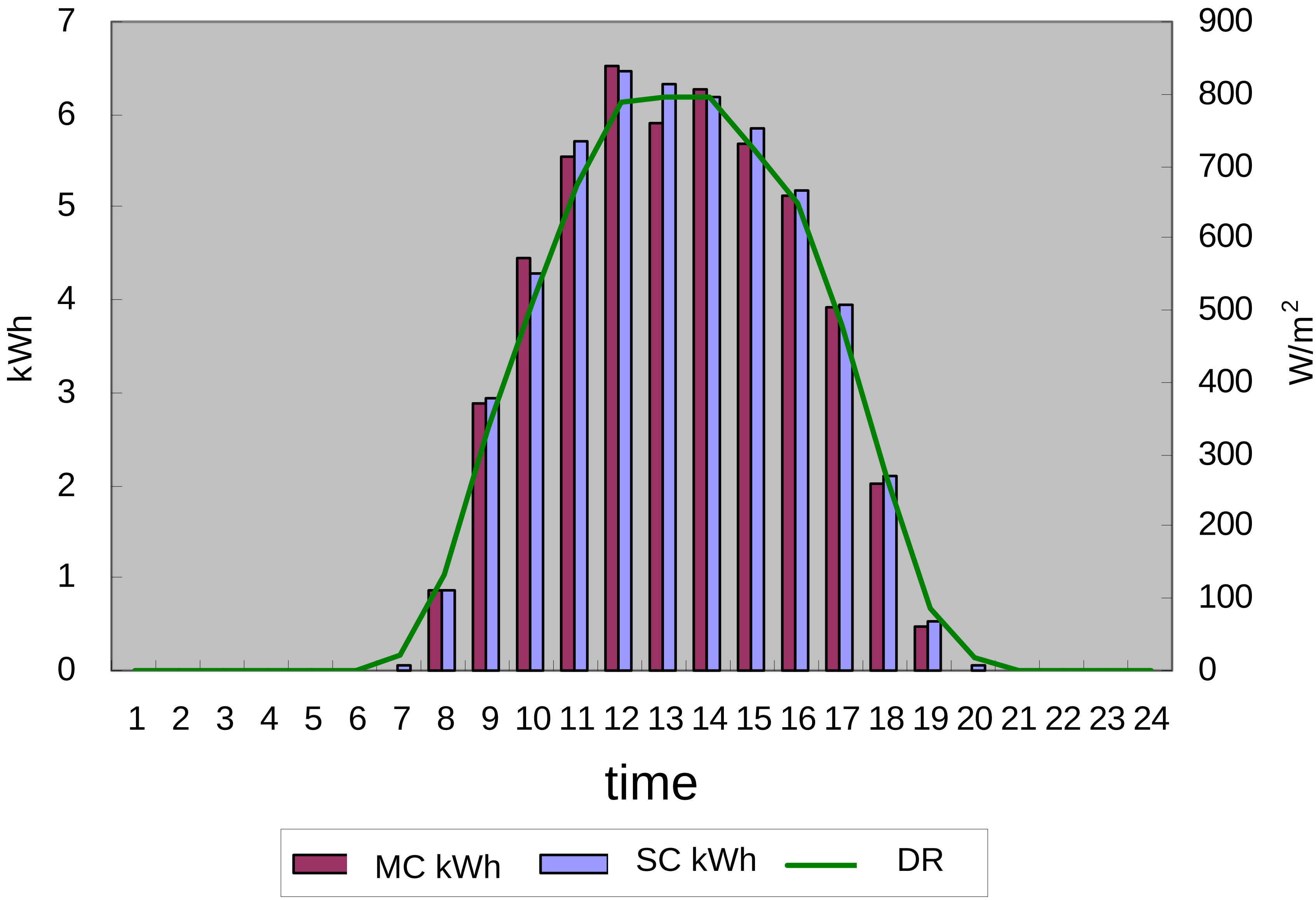
5 Monitoring and Control System

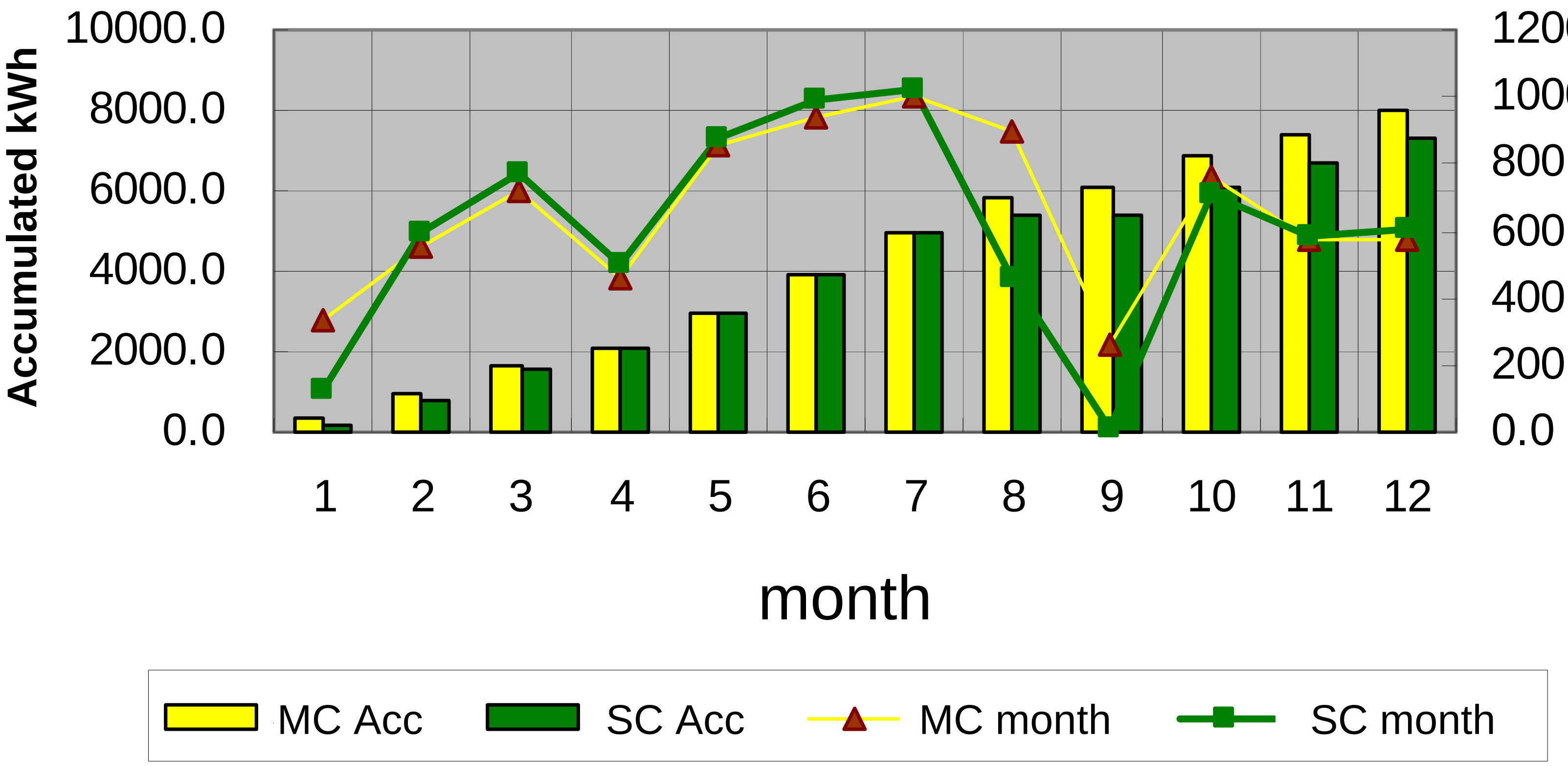
Photovoltaic Power Generation


W/m2
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
S 2002/10/02
C 2002/10/18
R 2002/10/22

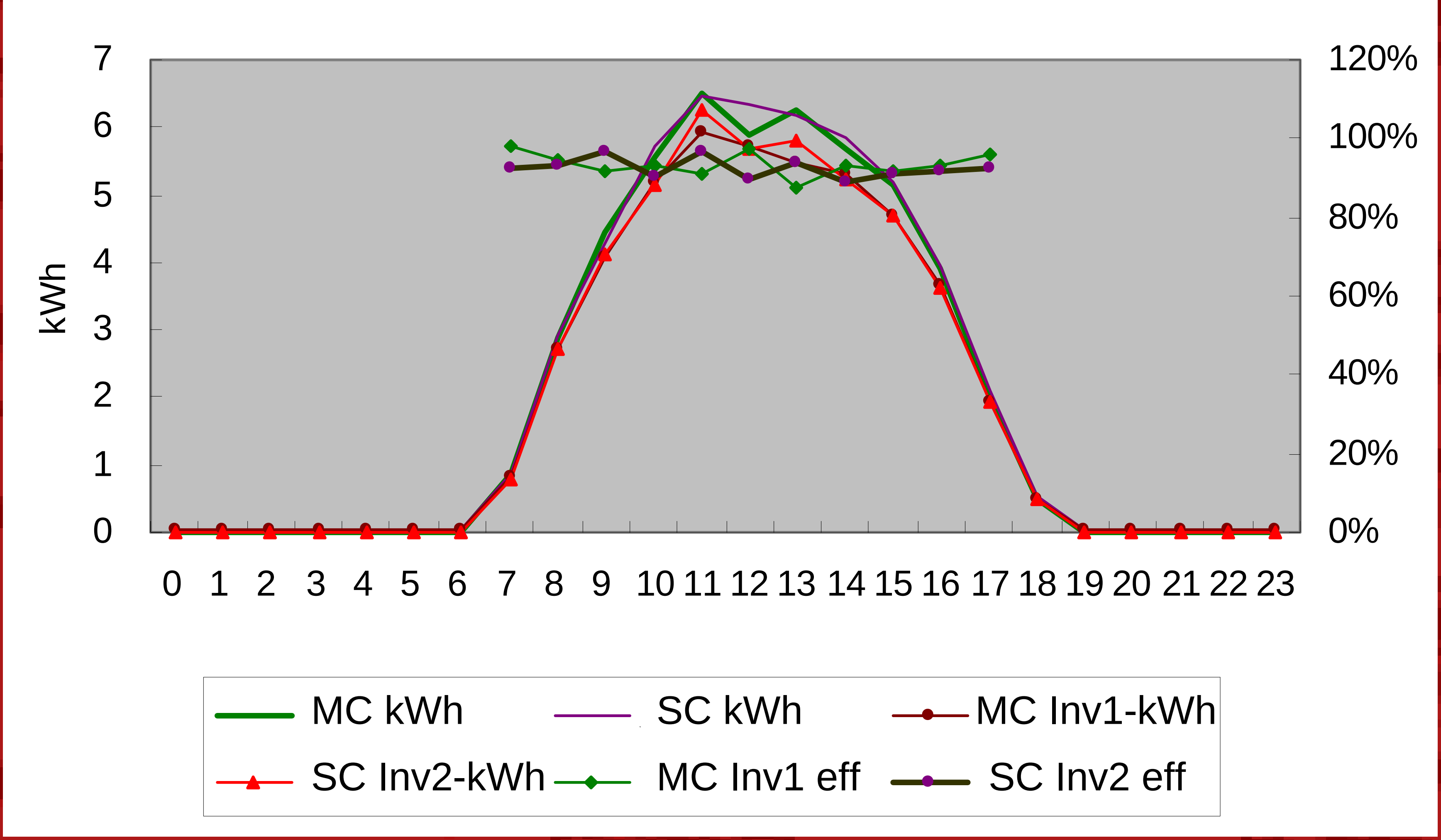


800
700
600
500
400
300
200
100
0
VDC / Daily Radiation (W/m2)
38
33
28
23
18
13
8
3
-2
IDC / temp / kWh
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
Time
MC VDC
SC VDC
Daily radiation
MC IDC
SC IDC
MC kWh
SC kWh
Outdoor temperature


7
6
5
4
3
2
1
0
kWh
900
800
700
600
500
400
300
200
100
0
W/m2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
time
MC kWh
SC kWh
DR

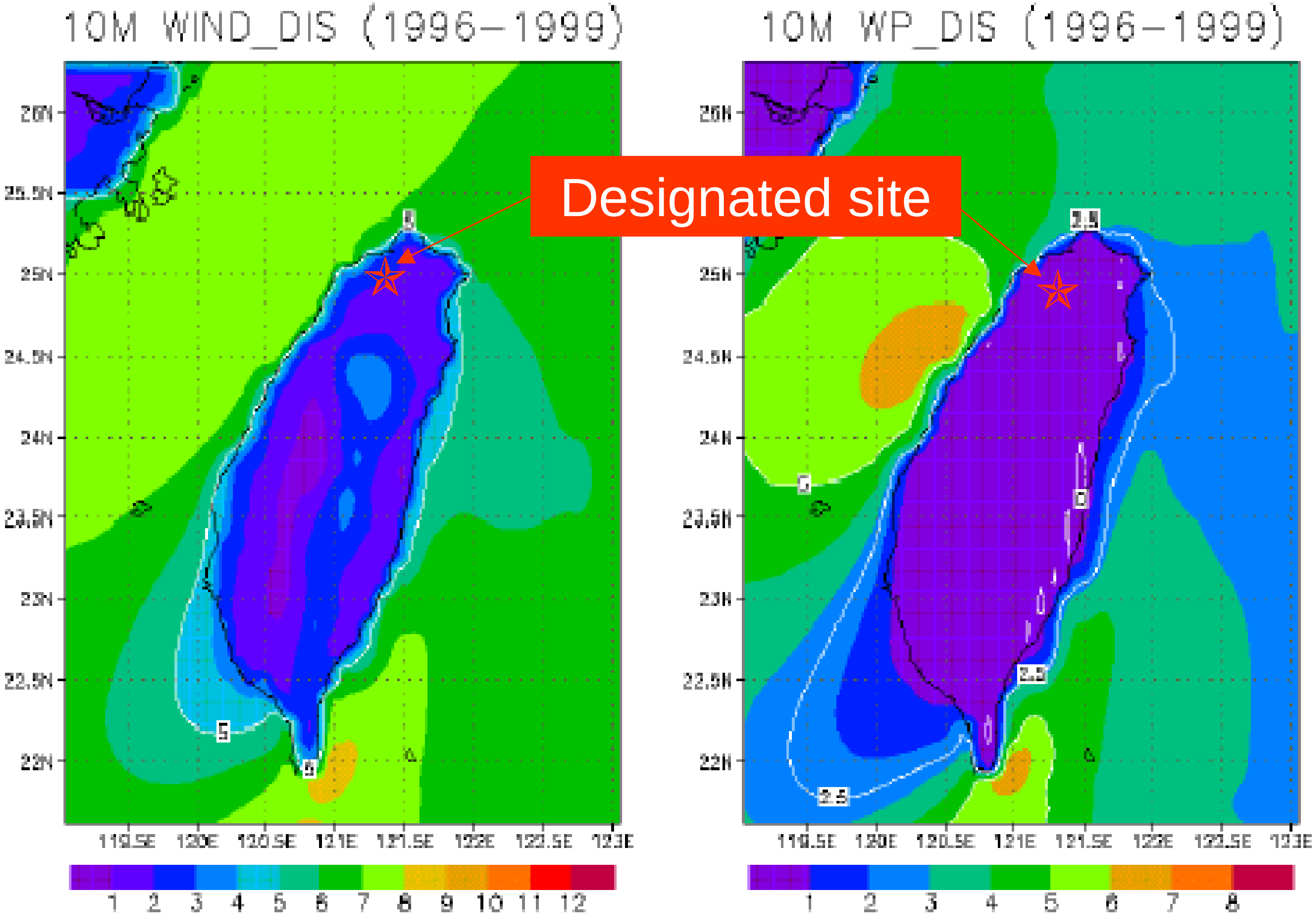


10000.0
8000.0
6000.0
4000.0
2000.0
0.0
Accumulated kWh
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
Monthly kWh
1
2
3
4
5
6
7
8
9
10
11
12
month
MC Acc
SC Acc
MC month
SC month



kWh
7
6
5
4
3
2
1
0
120%
100%
80%
60%
40%
20%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
MC kWh
SC kWh
MC Inv1-kWh
SC Inv2-kWh
MC Inv1 eff
SC Inv2 eff

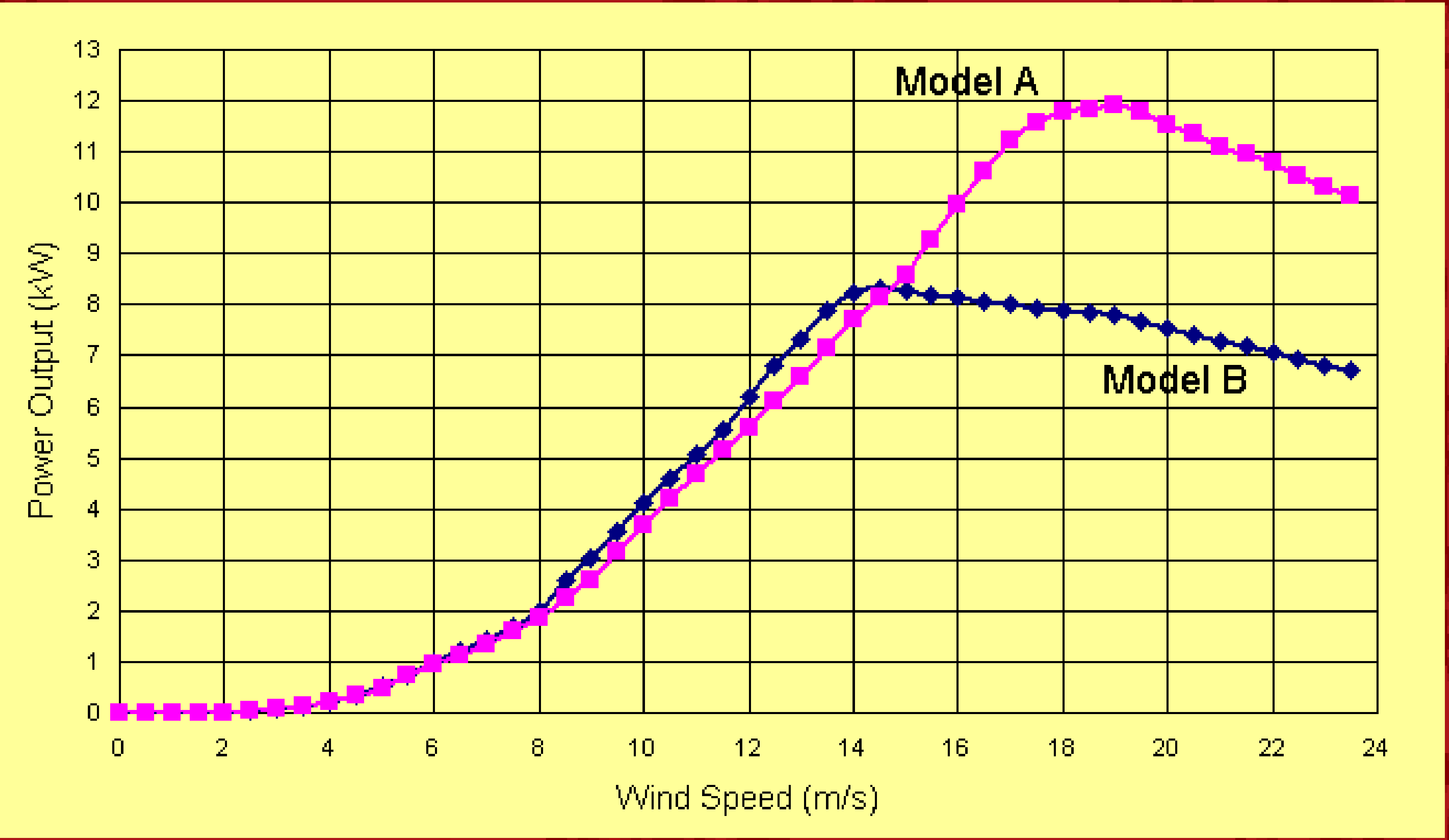
Wind Power Generation



Average wind speed (m/s)

Wind energy density (x 100 w/m^3)

Source: Energy Commission, Ministry of Economic Affairs (http://wind.erl.itri.org.tw)


Model A
Model B
Power Output (kW)
Wind Speed (m/s)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
0
2
4
6
8
10
12
14
16
18
20
22
24

Progress

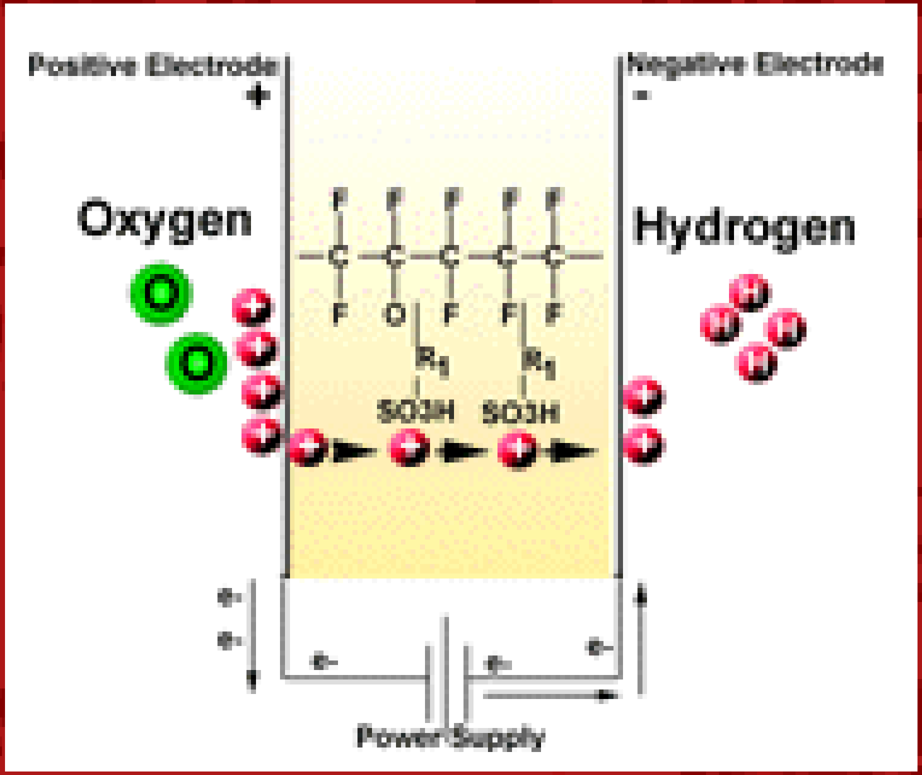
- Selection of place of installation completed
- A wind anemometer will be installed to assess the local wind power this year
- Concrete base platform will be built for both wind anemometer and turbine
- Conduits for power lines and data collection wires will be constructed

Remarks on Renewable Energy

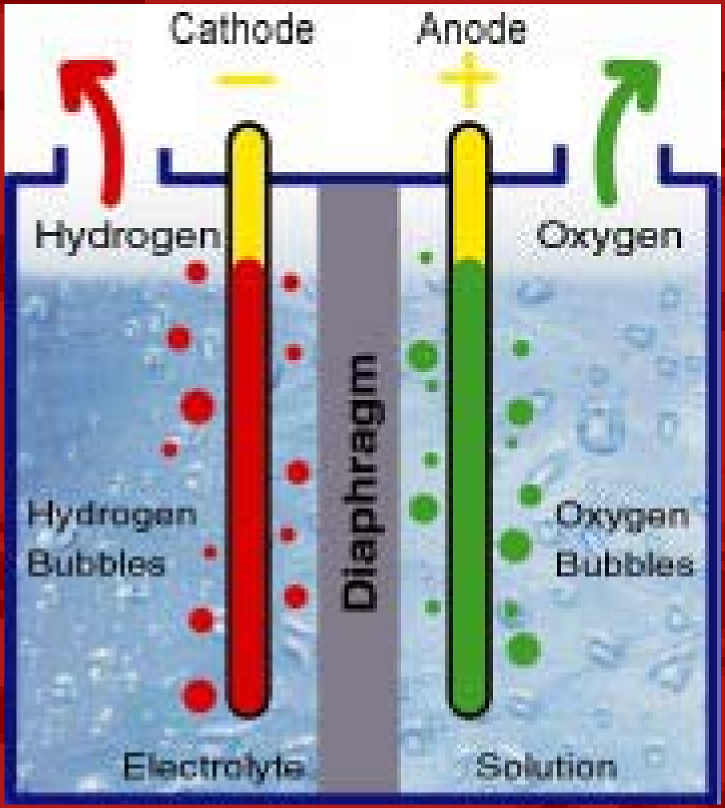
- The existing PV system generates a total of 15,297 kWh of electricity in a year yielding approximately 8.7 % of the total capacity
- Not expecting much electricity generated from the wind on site
- The maximum capacity of the fuel cells to be installed is 2 kW for continuous operation

Hydrogen Production and Storage

PEM Electrolysis



Alkaline Electrolysis



General Comparison of PEM & Alkaline Water Electrolysis

Characteristic	PEM Water Electrolysis	Alkaline Water Electrolysis
Stack Configuration/Cost	- More inherently costly materials of construction, especially catalysts and membranes - Capable of relatively high current densities, stack can be highly compact - Generally limited output capacity per stack to date	- Alkaline environment generally allows for use of less costly materials, especially catalysts and membranes - Typical current densities are lower than for PEMWE stacks, but still quite compact. - Commercial standard stack output is 15 NCMH
System Configuration/Cost	- System configuration is similar to AWE - Unproven for relatively large plants (e.g., typical maximum output of 10 NCMH)	- Commercial system configurations up to hundreds of NCMH capacity - Overall system size typically is comparable to PEMWE of similar output capacity
System Reliability	- Proven for highly engineered systems in submarines - Membrane is sensitive to impurities	- Proven commercial designs, relatively robust. Over 98% availability proven in field.

SPECIFICATIONS OF A PEM WATER ELECTROLYZER

Pure hydrogen output	Up to 1.0 Nm^3/hr	
Electrolyte system	Proton Exchange Membrane (PEM) Solid electrolyte, caustic free (no KOH)	
Maximum delivery pressure	13.8 bar (200 psig)	
Hydrogen purity	99.9 + % (99.999 + % optional)	
Hydrogen dew point	Down to –65 ^oC	
Water usage	Up to 1.0 liter/hr	
Water quality requirement	Deionized ASTM Type II (minimum)	
Electrical supply required	AC: 190 – 240 VAC, 1 phase, 50/60 hz 2 kVA – 12 kVA	DC: 60 – 200 VDC 150 A max
Operating environment	Indoor (outdoor optional)	
Dimensions (L x W x H)	97 cm x 105 cm x 106 cm)	
Weight	220 kg	
Shipping weight	250 kg	
Controls	Fully automatic and unattended operation	
Duty cycle	100 % (24 * 7)	
Installation	“Plug & Play” expedited installation	

Comparison of Methods of Hydrogen Storage

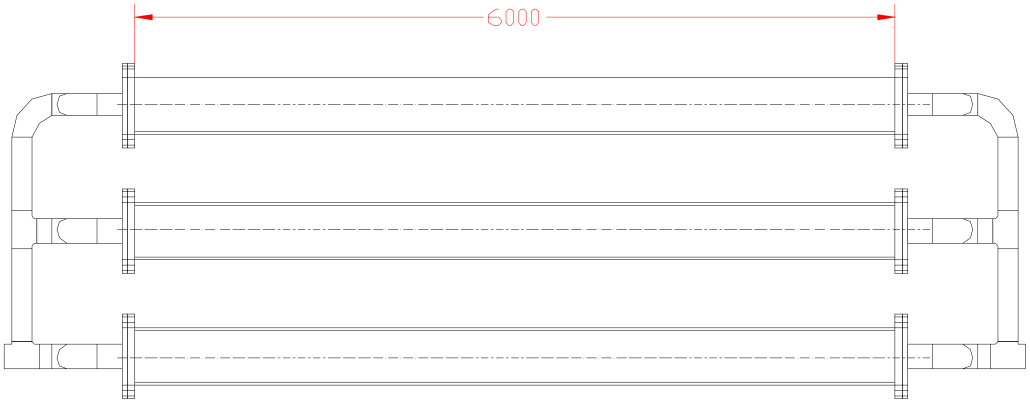
	Advantage	*Disadvantage*
System Pressure	♦ Low cost ♦ Simple operation ♦ Safety	♦ Bulky
Elevated Pressure	♦ Compact	♦ Consume power ♦ Complicated operation
Metal Hydride	♦ Compact ♦ Advanced technology	♦ Complicated operation ♦ High cost ♦ Heavy

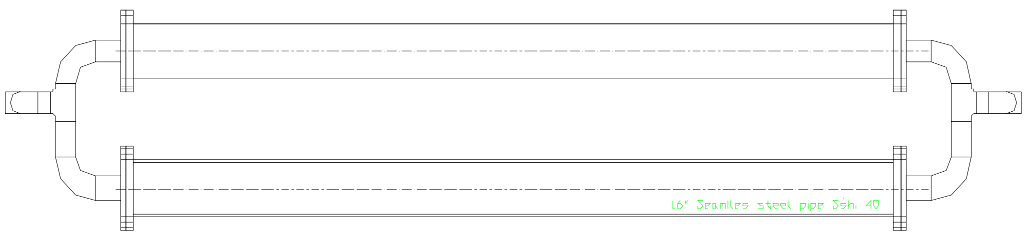
Metal Hydride and Hydrogen Storage

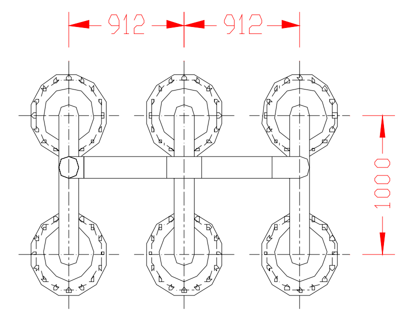
Storage Medium	Hydrogen Storage Capacity Wt %	g/ml	Energy Density cal/g	cal/ml
MgH_2	7	0.101	2373	3423
Mg_2NiH_4	3.16	0.081	1071	2745
VH_2	2.07	0.095	701	3227
$TiFeH_{1.95}$	1.75	0.096	593	3254
$LaNi_5H_7$	1.37	0.089	464	3017
Liquid Hydrogen	100	0.070	33900	2373
Gaseous Hydrogen	100	0.008	33900	271

Hydrogen Storage Capacity

- Case 1 : 2 kW fuel cells running 24 hours
  - 34.56 m^3 (STP) = 2.59 m^3 (200 psig)
  - 230 kg $MnNi_5$ metal hydride (< 55 liters)
- Case 2 : 2 kW fuel cells running 48 hours
  - 69.12 m^3 (STP) = 5.18 m^3 (200 psig)
  - 460 kg $MnNi_5$ metal hydride (< 110 liters)
- Case 3 : 2 kW fuel cells running 72 hours
  - 103.68 m^3 (STP) = 7.75 m^3 (200 psig)
  - 690 kg $MnNi_5$ metal hydride (< 165 liters)
- Case 4 : 2 kW fuel cells running 1 week
  - 241.92 m^3 (STP) = 18.08 m^3 (200 psig)
  - 1,600 kg $MnNi_5$ metal hydride (< 385 liters)







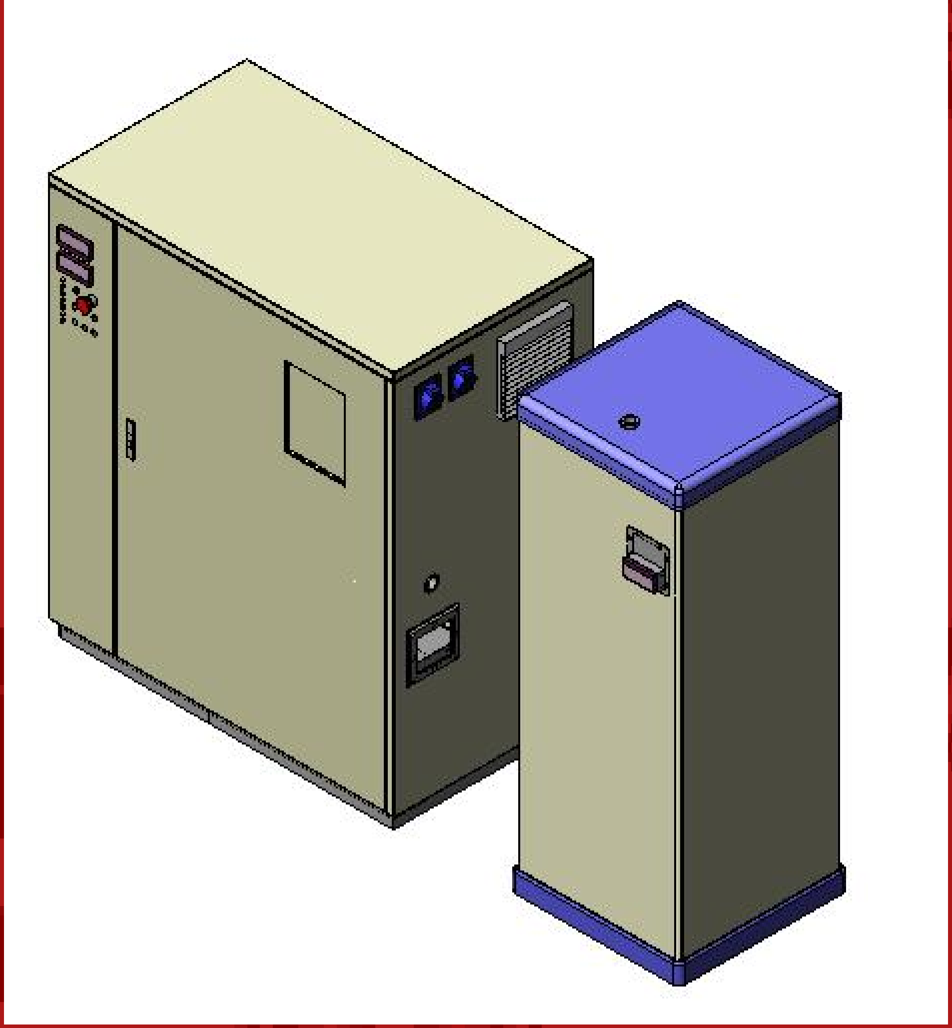
16" Seamlles steel pipe Ssh. 40

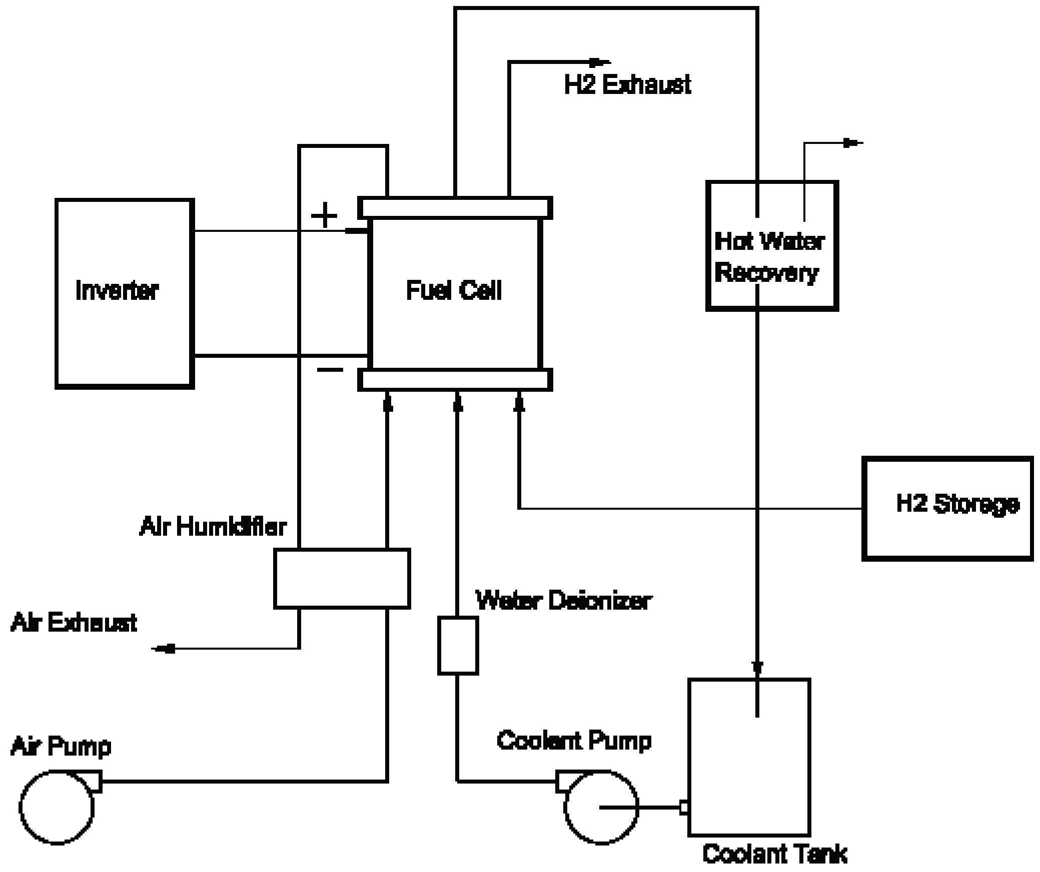
0.381*0.381*3.14159/4*6=0.684 (m3)

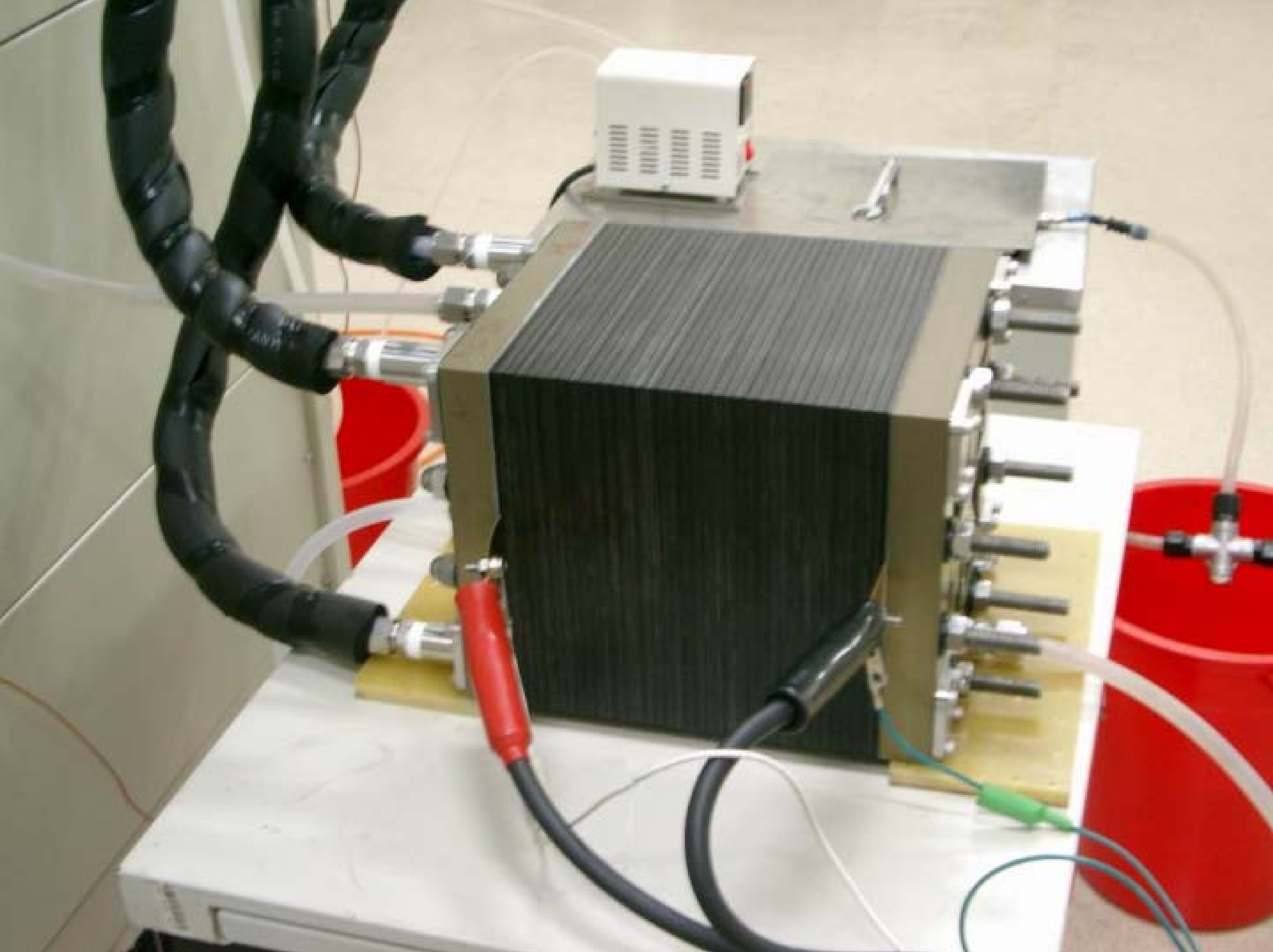
0.684 m3 * 12 = 8.208 m3

總重量約11000kg

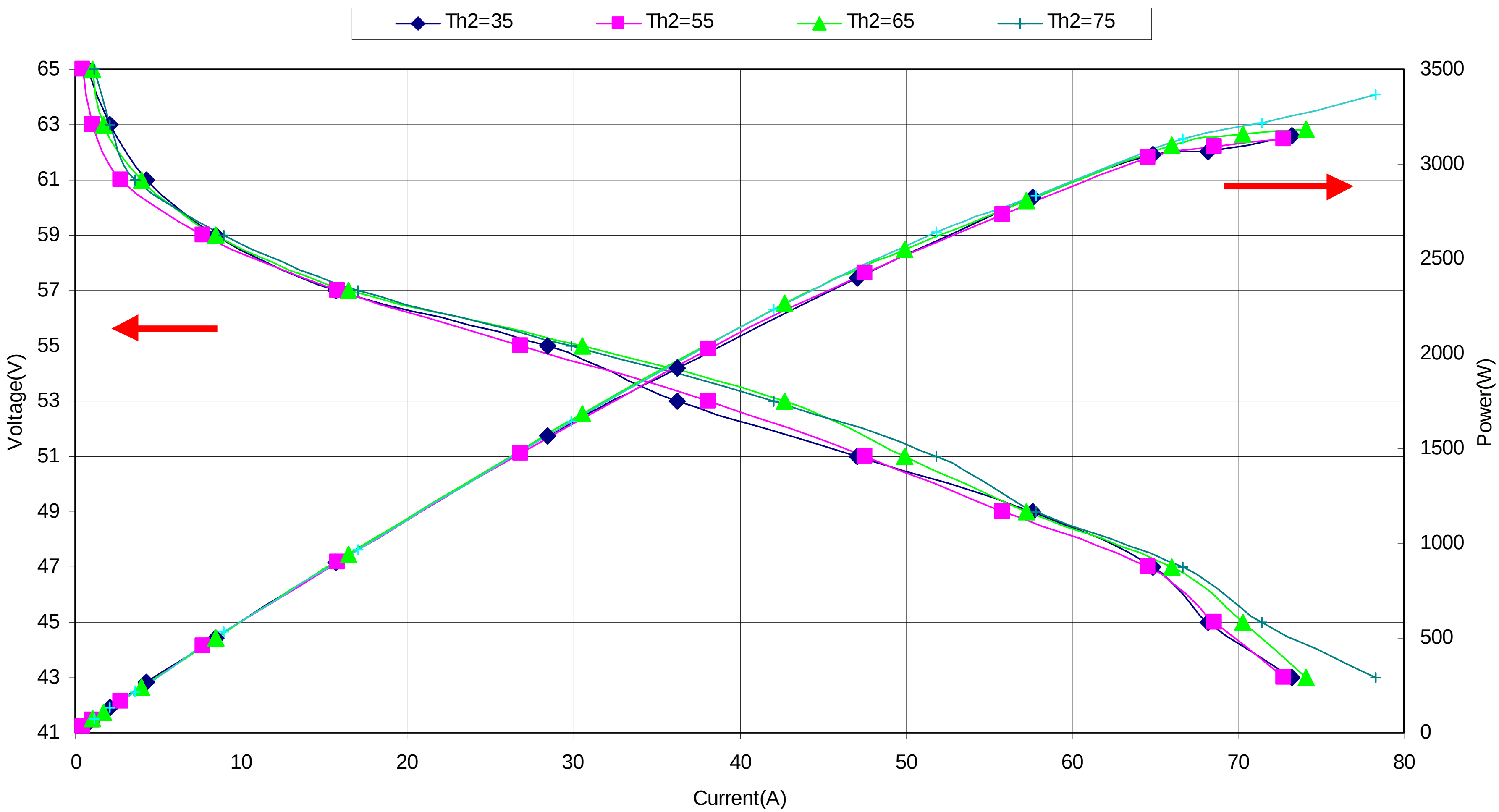
Fuel Cell Power Generation




H2 Exhaust
Inverter
Fuel Cell
Hot Water
Recovery
H2 Storage
Air Humidifier
Water Deionizer
Air Exhaust
Air Pump
Coolant Pump
Coolant Tank



I-V comparison under different H2 Humidifier tempatures



Concluding Remarks

- Hydrogen may serve as a means of storing electricity in support of distributed renewable energy based system efficiently and friendly to the environments through the use of fuel cells.
- An integrated renewable energy/fuel cell power generation system has been designed and details of the components of the system were presented.
- In addition to utilizing renewable energy more effectively, the hydrogen generator in this system could be used as a tool for load management balancing peak and off-peak electricity demand.