



Our Solar Grid –Tie with Battery Backup
Presented at the Bowen Island Solar Power Forum , 4 Apr. 2016
Phil Gregory (gregory@phas.ubc.ca)

Solar Electricity Options

- 1) Off grid.
 - Need a battery to store excess power production and use at night.

- 2) Grid tie with no battery. (very efficient > 95%)
 - Use the grid as a very efficient storage battery to store your excess.
 - Not able to produce any power when the grid goes down.

- 3) Grid tie with battery.
 - Still have power when the electricity grid is down.
 - Overall efficiency converting solar energy from my panels to 220/120 V AC: **68% in summer, 45% in winter**

Our 3.9 kW system provides 20% of our electrical power

Phil Gregory's Solar Power

Feb. 2015

Solar Modules



DC to DC converter



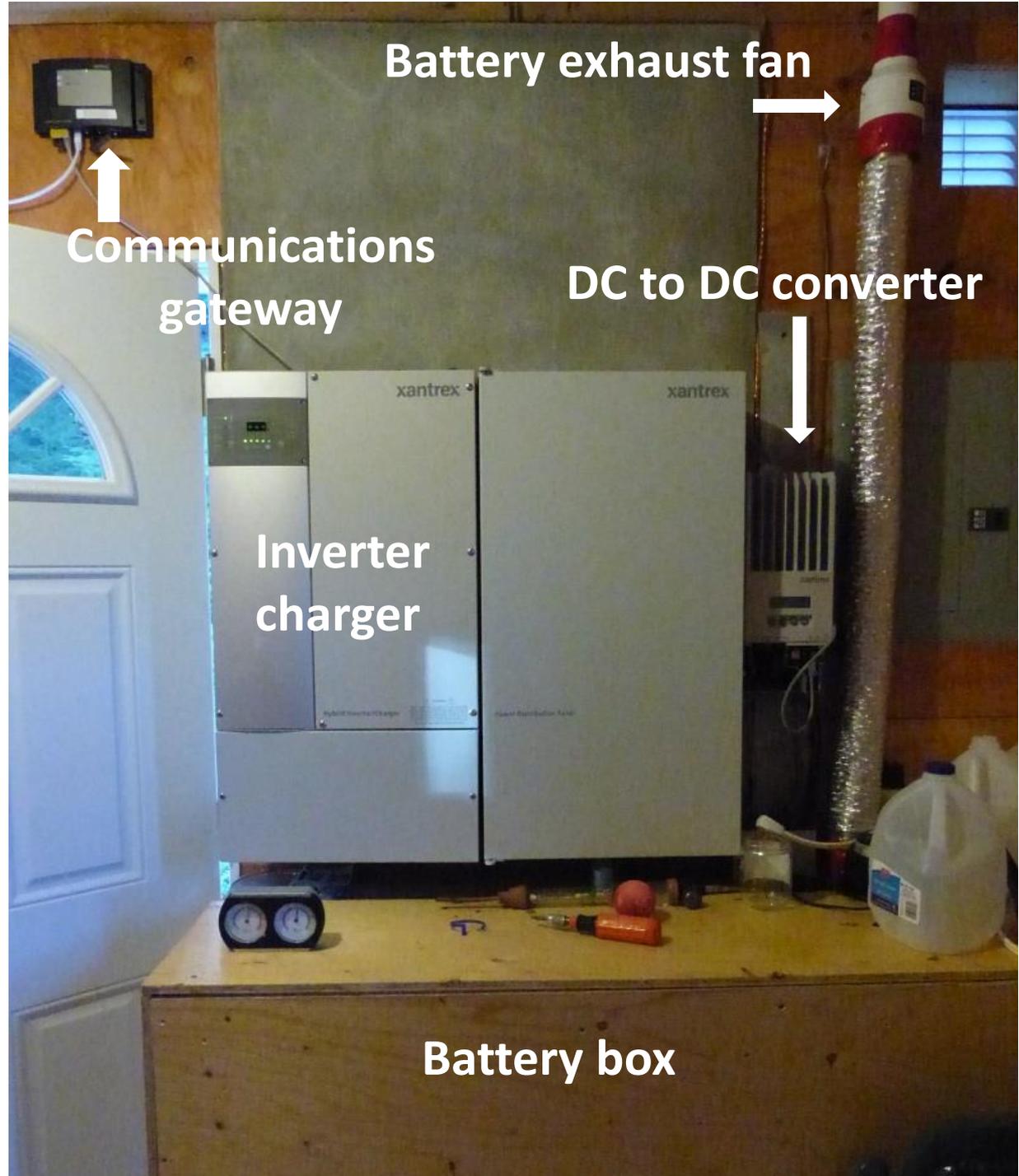
24 V Battery



4 kW Inverter/charger

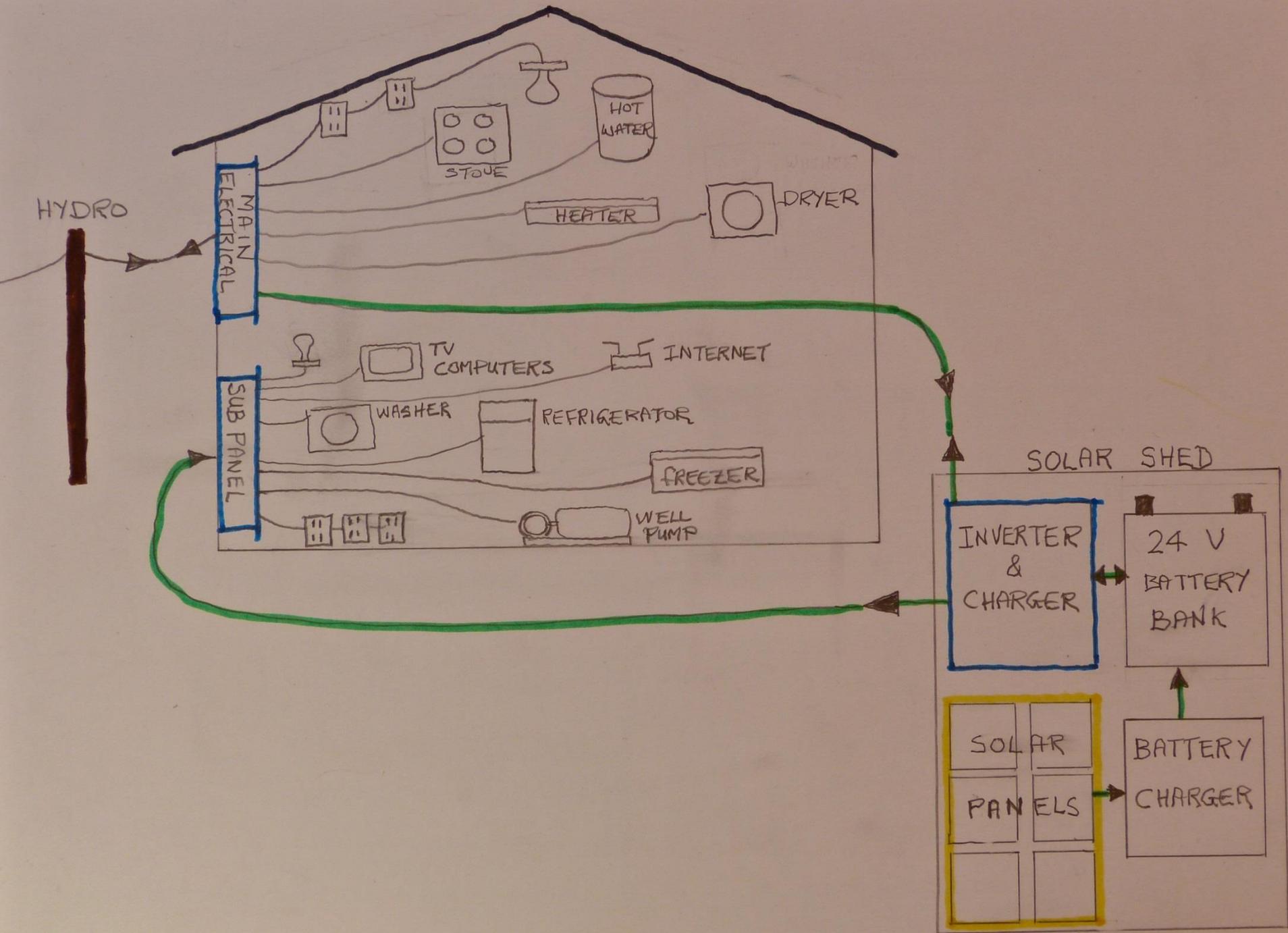


220 V AC Electrical & Intranet
connection to house





DIRECTORY / DIRECTOIRE
 40
 38
 36
 34
 32
 30
 28
 26
 24
 22
 20
 18
 16
 14
 12
 10
 8
 6
 4
 2
 1
 3
 5
 7
 9
 11
 13
 15
 17
 19
 21
 23
 25
 27
 29
 31
 33
 35
 37
 39
 41
 43
 45
 47
 49
 51
 53
 55
 57
 59
 61
 63
 65
 67
 69
 71
 73
 75
 77
 79
 81
 83
 85
 87
 89
 91
 93
 95
 97
 99
 101
 103
 105
 107
 109
 111
 113
 115
 117
 119
 121
 123
 125
 127
 129
 131
 133
 135
 137
 139
 141
 143
 145
 147
 149
 151
 153
 155
 157
 159
 161
 163
 165
 167
 169
 171
 173
 175
 177
 179
 181
 183
 185
 187
 189
 191
 193
 195
 197
 199
 201
 203
 205
 207
 209
 211
 213
 215
 217
 219
 221
 223
 225
 227
 229
 231
 233
 235
 237
 239
 241
 243
 245
 247
 249
 251
 253
 255
 257
 259
 261
 263
 265
 267
 269
 271
 273
 275
 277
 279
 281
 283
 285
 287
 289
 291
 293
 295
 297
 299
 301
 303
 305
 307
 309
 311
 313
 315
 317
 319
 321
 323
 325
 327
 329
 331
 333
 335
 337
 339
 341
 343
 345
 347
 349
 351
 353
 355
 357
 359
 361
 363
 365
 367
 369
 371
 373
 375
 377
 379
 381
 383
 385
 387
 389
 391
 393
 395
 397
 399
 401
 403
 405
 407
 409
 411
 413
 415
 417
 419
 421
 423
 425
 427
 429
 431
 433
 435
 437
 439
 441
 443
 445
 447
 449
 451
 453
 455
 457
 459
 461
 463
 465
 467
 469
 471
 473
 475
 477
 479
 481
 483
 485
 487
 489
 491
 493
 495
 497
 499
 501
 503
 505
 507
 509
 511
 513
 515
 517
 519
 521
 523
 525
 527
 529
 531
 533
 535
 537
 539
 541
 543
 545
 547
 549
 551
 553
 555
 557
 559
 561
 563
 565
 567
 569
 571
 573
 575
 577
 579
 581
 583
 585
 587
 589
 591
 593
 595
 597
 599
 601
 603
 605
 607
 609
 611
 613
 615
 617
 619
 621
 623
 625
 627
 629
 631
 633
 635
 637
 639
 641
 643
 645
 647
 649
 651
 653
 655
 657
 659
 661
 663
 665
 667
 669
 671
 673
 675
 677
 679
 681
 683
 685
 687
 689
 691
 693
 695
 697
 699
 701
 703
 705
 707
 709
 711
 713
 715
 717
 719
 721
 723
 725
 727
 729
 731
 733
 735
 737
 739
 741
 743
 745
 747
 749
 751
 753
 755
 757
 759
 761
 763
 765
 767
 769
 771
 773
 775
 777
 779
 781
 783
 785
 787
 789
 791
 793
 795
 797
 799
 801
 803
 805
 807
 809
 811
 813
 815
 817
 819
 821
 823
 825
 827
 829
 831
 833
 835
 837
 839
 841
 843
 845
 847
 849
 851
 853
 855
 857
 859
 861
 863
 865
 867
 869
 871
 873
 875
 877
 879
 881
 883
 885
 887
 889
 891
 893
 895
 897
 899
 901
 903
 905
 907
 909
 911
 913
 915
 917
 919
 921
 923
 925
 927
 929
 931
 933
 935
 937
 939
 941
 943
 945
 947
 949
 951
 953
 955
 957
 959
 961
 963
 965
 967
 969
 971
 973
 975
 977
 979
 981
 983
 985
 987
 989
 991
 993
 995
 997
 999
 1001
 1003
 1005
 1007
 1009
 1011
 1013
 1015
 1017
 1019
 1021
 1023
 1025
 1027
 1029
 1031
 1033
 1035
 1037
 1039
 1041
 1043
 1045
 1047
 1049
 1051
 1053
 1055
 1057
 1059
 1061
 1063
 1065
 1067
 1069
 1071
 1073
 1075
 1077
 1079
 1081
 1083
 1085
 1087
 1089
 1091
 1093
 1095
 1097
 1099
 1101
 1103
 1105
 1107
 1109
 1111
 1113
 1115
 1117
 1119
 1121
 1123
 1125
 1127
 1129
 1131
 1133
 1135
 1137
 1139
 1141
 1143
 1145
 1147
 1149
 1151
 1153
 1155
 1157
 1159
 1161
 1163
 1165
 1167
 1169
 1171
 1173
 1175
 1177
 1179
 1181
 1183
 1185
 1187
 1189
 1191
 1193
 1195
 1197
 1199
 1201
 1203
 1205
 1207
 1209
 1211
 1213
 1215
 1217
 1219
 1221
 1223
 1225
 1227
 1229
 1231
 1233
 1235
 1237
 1239
 1241
 1243
 1245
 1247
 1249
 1251
 1253
 1255
 1257
 1259
 1261
 1263
 1265
 1267
 1269
 1271
 1273
 1275
 1277
 1279
 1281
 1283
 1285
 1287
 1289
 1291
 1293
 1295
 1297
 1299
 1301
 1303
 1305
 1307
 1309
 1311
 1313
 1315
 1317
 1319
 1321
 1323
 1325
 1327
 1329
 1331
 1333
 1335
 1337
 1339
 1341
 1343
 1345
 1347
 1349
 1351
 1353
 1355
 1357
 1359
 1361
 1363
 1365
 1367
 1369
 1371
 1373
 1375
 1377
 1379
 1381
 1383
 1385
 1387
 1389
 1391
 1393
 1395
 1397
 1399
 1401
 1403
 1405
 1407
 1409
 1411
 1413
 1415
 1417
 1419
 1421
 1423
 1425
 1427
 1429
 1431
 1433
 1435
 1437
 1439
 1441
 1443
 1445
 1447
 1449
 1451
 1453
 1455
 1457
 1459
 1461
 1463
 1465
 1467
 1469
 1471
 1473
 1475
 1477
 1479
 1481
 1483
 1485
 1487
 1489
 1491
 1493
 1495
 1497
 1499
 1501
 1503
 1505
 1507
 1509
 1511
 1513
 1515
 1517
 1519
 1521
 1523
 1525
 1527
 1529
 1531
 1533
 1535
 1537
 1539
 1541
 1543
 1545
 1547
 1549
 1551
 1553
 1555
 1557
 1559
 1561
 1563
 1565
 1567
 1569
 1571
 1573
 1575
 1577
 1579
 1581
 1583
 1585
 1587
 1589
 1591
 1593
 1595
 1597
 1599
 1601
 1603
 1605
 1607
 1609
 1611
 1613
 1615
 1617
 1619
 1621
 1623
 1625
 1627
 1629
 1631
 1633
 1635
 1637
 1639
 1641
 1643
 1645
 1647
 1649
 1651
 1653
 1655
 1657
 1659
 1661
 1663
 1665
 1667
 1669
 1671
 1673
 1675
 1677
 1679
 1681
 1683
 1685
 1687
 1689
 1691
 1693
 1695
 1697
 1699
 1701
 1703
 1705
 1707
 1709
 1711
 1713
 1715
 1717
 1719
 1721
 1723
 1725
 1727
 1729
 1731
 1733
 1735
 1737
 1739
 1741
 1743
 1745
 1747
 1749
 1751
 1753
 1755
 1757
 1759
 1761
 1763
 1765
 1767
 1769
 1771
 1773
 1775
 1777
 1779
 1781
 1783
 1785
 1787
 1789
 1791
 1793
 1795
 1797
 1799
 1801
 1803
 1805
 1807
 1809
 1811
 1813
 1815
 1817
 1819
 1821
 1823
 1825
 1827
 1829
 1831
 1833
 1835
 1837
 1839
 1841
 1843
 1845
 1847
 1849
 1851
 1853
 1855
 1857
 1859
 1861
 1863
 1865
 1867
 1869
 1871
 1873
 1875
 1877
 1879
 1881
 1883
 1885
 1887
 1889
 1891
 1893
 1895
 1897
 1899
 1901
 1903
 1905
 1907
 1909
 1911
 1913
 1915
 1917
 1919
 1921
 1923
 1925
 1927
 1929
 1931
 1933
 1935
 1937
 1939
 1941
 1943
 1945
 1947
 1949
 1951
 1953
 1955
 1957
 1959
 1961
 1963
 1965
 1967
 1969
 1971
 1973
 1975
 1977
 1979
 1981
 1983
 1985
 1987
 1989
 1991
 1993
 1995
 1997
 1999
 2001
 2003
 2005
 2007
 2009
 2011
 2013
 2015
 2017
 2019
 2021
 2023
 2025
 2027
 2029
 2031
 2033
 2035
 2037
 2039
 2041
 2043
 2045
 2047
 2049
 2051
 2053
 2055
 2057
 2059
 2061
 2063
 2065
 2067
 2069
 2071
 2073
 2075
 2077
 2079
 2081
 2083
 2085
 2087
 2089
 2091
 2093
 2095
 2097
 2099
 2101
 2103
 2105
 2107
 2109
 2111
 2113
 2115
 2117
 2119
 2121
 2123
 2125
 2127
 2129
 2131
 2133
 2135
 2137
 2139
 2141
 2143
 2145
 2147
 2149
 2151
 2153
 2155
 2157
 2159
 2161
 2163
 2165
 2167
 2169
 2171
 2173
 2175
 2177
 2179
 2181
 2183
 2185
 2187
 2189
 2191
 2193
 2195
 2197
 2199
 2201
 2203
 2205
 2207
 2209
 2211
 2213
 2215
 2217
 2219
 2221
 2223
 2225
 2227
 2229
 2231
 2233
 2235
 2237
 2239
 2241
 2243
 2245
 2247
 2249
 2251
 2253
 2255
 2257
 2259
 2261
 2263
 2265
 2267
 2269
 2271
 2273
 2275
 2277
 2279
 2281
 2283
 2285
 2287
 2289
 2291
 2293
 2295
 2297
 2299
 2301
 2303
 2305
 2307
 2309
 2311
 2313
 2315
 2317
 2319
 2321
 2323
 2325
 2327
 2329
 2331
 2333
 2335
 2337
 2339
 2341
 2343
 2345
 2347
 2349
 2351
 2353
 2355
 2357
 2359
 2361
 2363
 2365
 2367
 2369
 2371
 2373
 2375
 2377
 2379
 2381
 2383
 2385
 2387
 2389
 2391
 2393
 2395
 2397
 2399
 2401
 2403
 2405
 2407
 2409
 2411
 2413
 2415
 2417
 2419
 2421
 2423
 2425
 2427
 2429
 2431
 2433
 2435
 2437
 2439
 2441
 2443
 2445
 2447
 2449
 2451
 2453
 2455
 2457
 2459
 2461
 2463
 2465
 2467
 2469
 2471
 2473
 2475
 2477
 2479
 2481
 2483
 2485
 2487
 2489
 2491
 2493
 2495
 2497
 2499
 2501
 2503
 2505
 2507
 2509
 2511
 2513
 2515
 2517
 2519
 2521
 2523
 2525
 2527
 2529
 2531
 2533
 2535
 2537
 2539
 2541
 2543
 2545
 2547
 2549
 2551
 2553
 2555
 2557
 2559
 2561
 2563
 2565
 2567
 2569
 2571
 2573
 2575
 2577
 2579
 2581
 2583
 2585
 2587
 2589
 2591
 2593
 2595
 2597
 2599
 2601
 2603
 2605
 2607
 2609
 2611
 2613
 2615
 2617
 2619
 2621
 2623
 2625
 2627
 2629
 2631
 2633
 2635
 2637
 2639
 2641
 2643
 2645
 2647
 2649
 2651
 2653
 2655
 2657
 2659
 2661
 2663
 2665
 2667
 2669
 2671
 2673
 2675
 2677
 2679
 2681
 2683
 2685
 2687
 2689
 2691
 2693
 2695
 2697
 2699
 2701
 2703
 2705
 2707
 2709
 2711
 2713
 2715
 2717
 2719
 2721
 2723
 2725
 2727
 2729
 2731
 2733
 2735
 2737
 2739
 2741
 2743
 2745
 2747
 2749
 2751
 2753
 2755
 2757
 2759
 2761
 2763
 2765
 2767
 2769
 2771
 2773
 2775
 2777
 2779
 2781
 2783
 2785
 2787
 2789
 2791
 2793
 2795
 2797
 2799
 2801
 2803
 2805
 2807
 2809
 2811
 2813
 2815
 2817
 2819
 2821
 2823
 2825
 2827
 2829
 2831
 2833
 2835



Costs

First phase 2008 (8 x 200 W panels = 1600 W)

8 Sanyo panels (\$5.85 per W)	=	\$9368
Xantrex 4 kW 120/240 W Inverter/Charge	=	\$4873
Control panel + charge controller + gateway	=	\$2086
Mounting rails	=	\$ 980
Batteries (24 V, 24 kWh capacity) + shipping	=	\$5343 (\$6555 in 2016)
Labour + electrical supplies + safety permit +GST	=	\$8205
Phase 1 total	-----	= \$30,855

Second phase 2015 (9 x 260 W panels = 2340 W)

9+1 spare Canadian Solar panels (\$0.94 per W)	=	\$2440
Mounting rails	=	\$ 615
2 charge controllers	=	\$1502
Electrical supplies + safety permit (\$239)	=	\$ 912
Labour + travel	=	\$1373
GST	=	\$ 263
Phase 1 total	-----	= \$ 7,105

Total ----- = \$37,960

Estimated cost of my system today

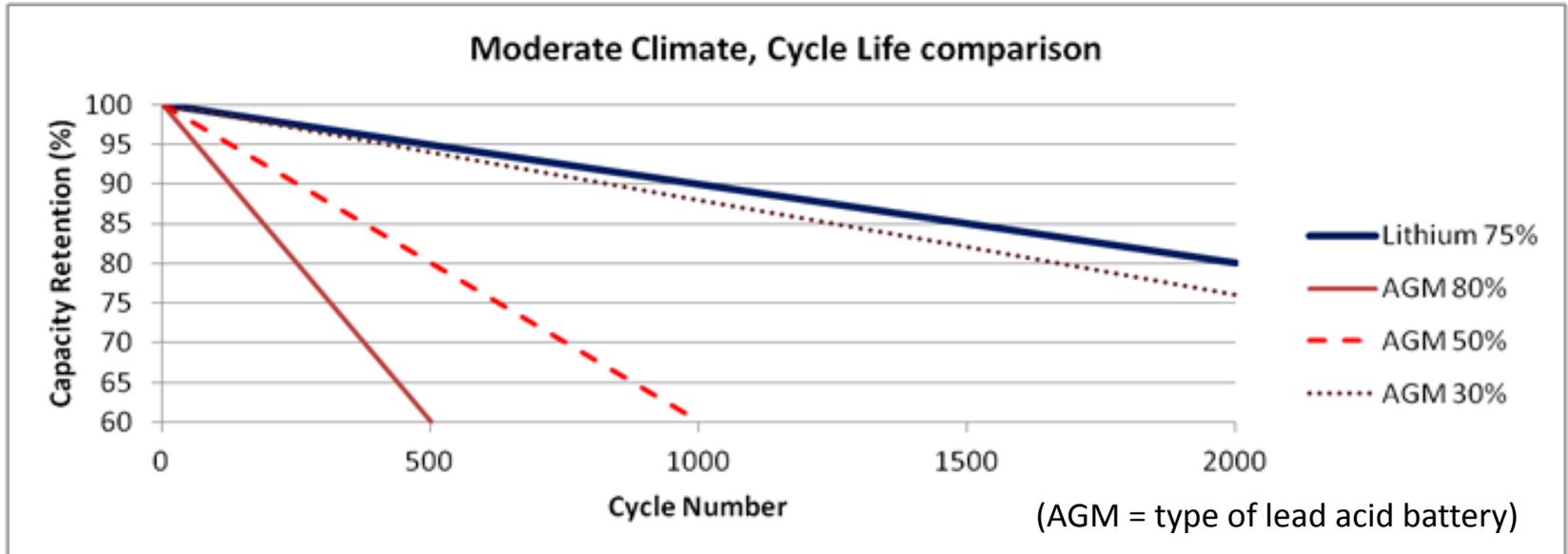
3900 W grid tie with battery

15 x 260 W panels = 3900 W (\$1 per W)	= \$3900
4 kW 120/240 W Inverter/Charge	= \$3500
Control panel + 3 charge controllers + gateway	= \$3600
Mounting rails	= \$1200
Batteries (24 V, 24 kWh capacity) + shipping	= \$6555
Labour + electrical supplies + safety permit +GST	= \$10000
Total -----	= \$25,155
Cost per W = \$6.45	

3900 W grid tie NO battery

15 x 260 W panels = 3900 W (\$1 per W)	= \$3900
8 micro-inverters	= \$2300
Monitoring unit	= \$ 600
Mounting rails	= \$1200
Labour + electrical supplies + safety permit +GST	= \$5000
Total -----	= \$13,000
Cost per W = \$3.34	

Battery life issues



A Comparison of Lead Acid and Lithium-ion in Stationary Storage Application, Greg Albright, Jake Edie, Said Al-Hallaj, AltEnergyMag, 2012, http://www.altenergymag.com/content.php?post_type=1884

Bowen Island power outages

Typical significant power outage duration = 8 hr

Average load during outage = 0.4 kW

Battery discharge = $8 \times 0.4 = 3.2$ kWh

My battery rated at 24 kWh

Battery discharge for an 8 hr outage = 24 %

Tesla Powerwall Li-ion batteries

Advertise 6.4 kWh units for \$3500 US or \$4500 CAD

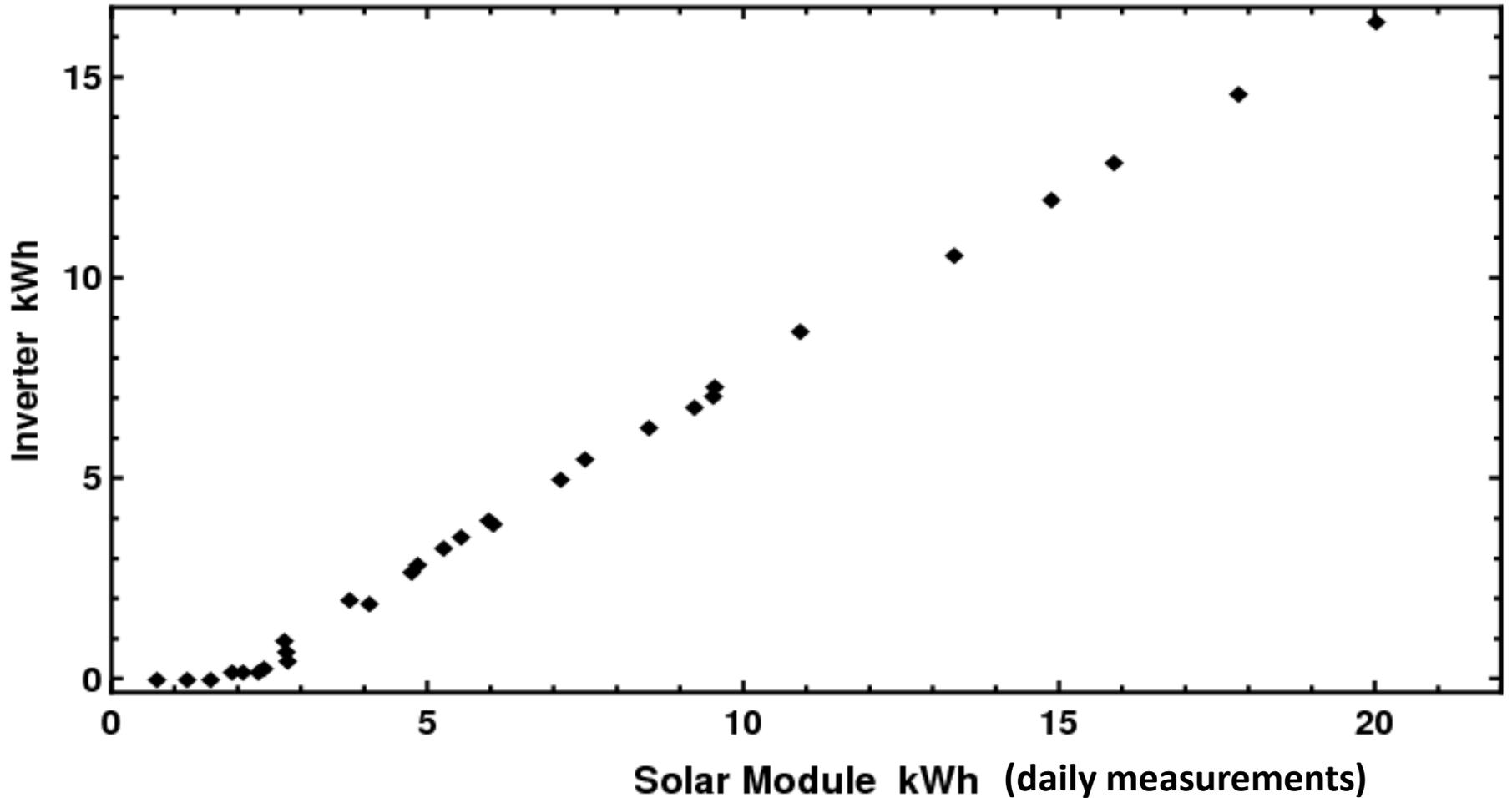
\$16900 CAD to replace my 24 kWh battery capacity. That's 2.6 times the cost of lead acid but because Li-ion can be more deeply cycled for a similar or longer lifetime, one could probably get by with a smaller battery capacity.

Advantages: 92% efficiency, no maintenance, more environmentally friendly to produce

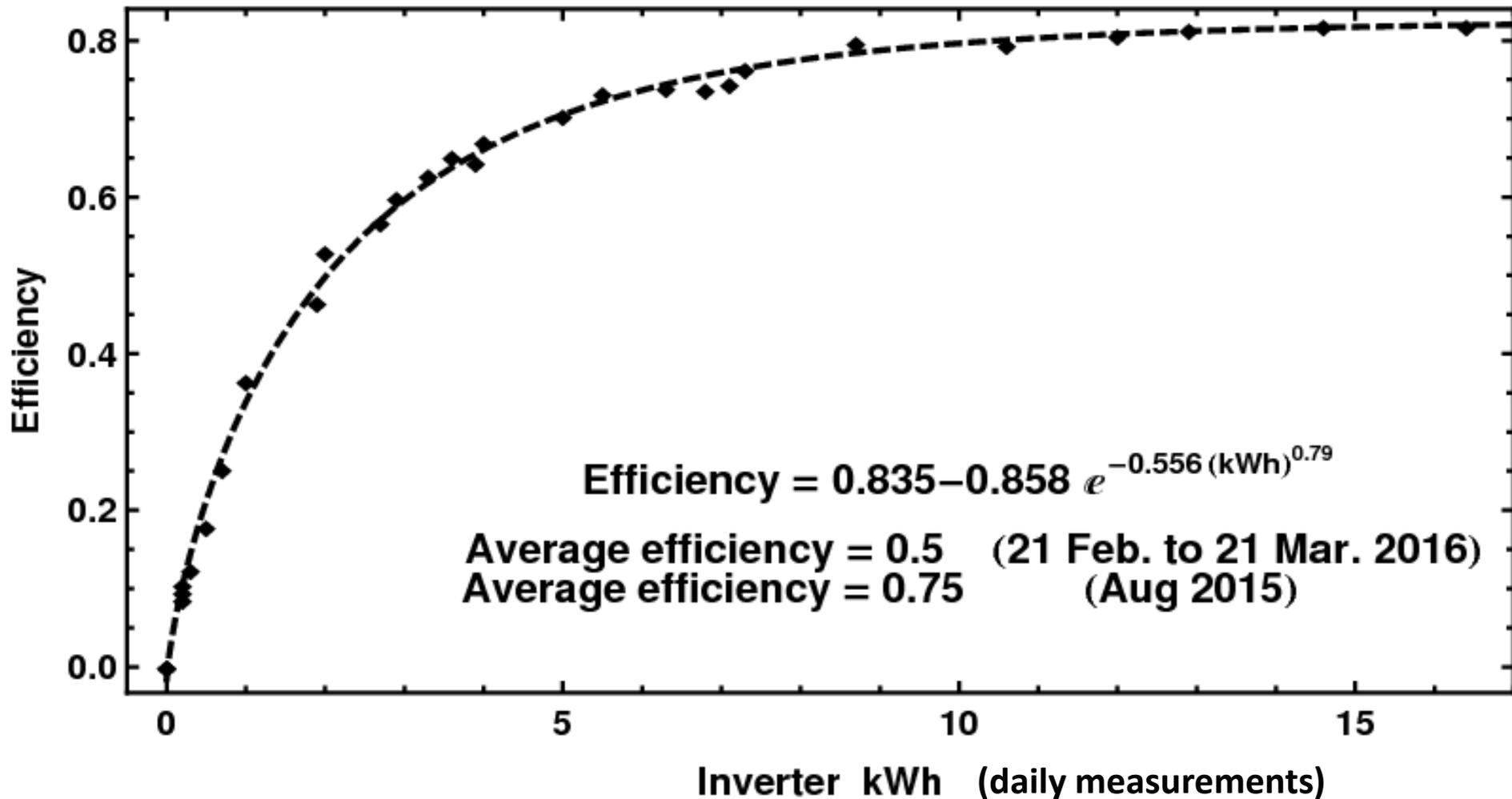
Disadvantage: The likelihood and consequences of a thermal runaway event are higher for lithium-ion. It has a higher amount of energy in a smaller volume. On the other hand a flooded lead acid batteries produce hydrogen gas which needs to be vented for safe operation.



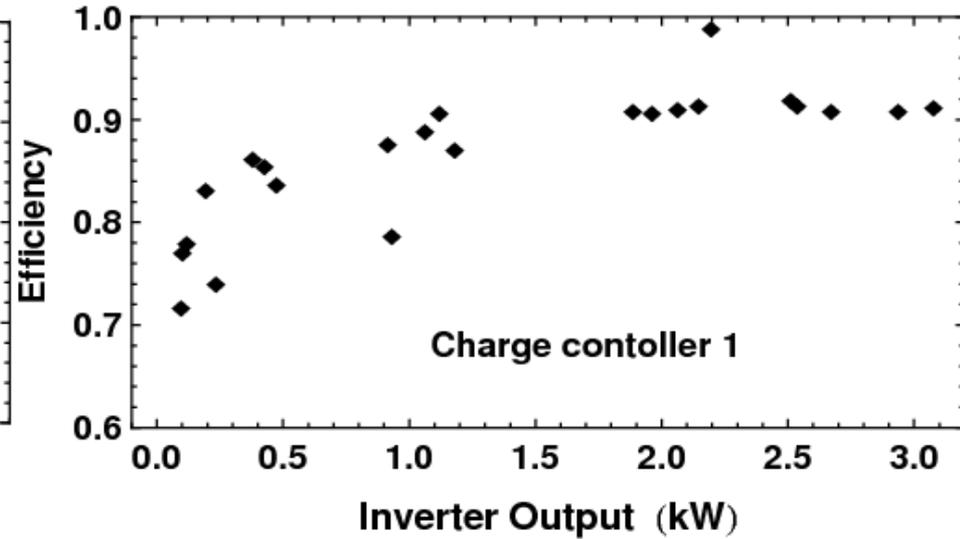
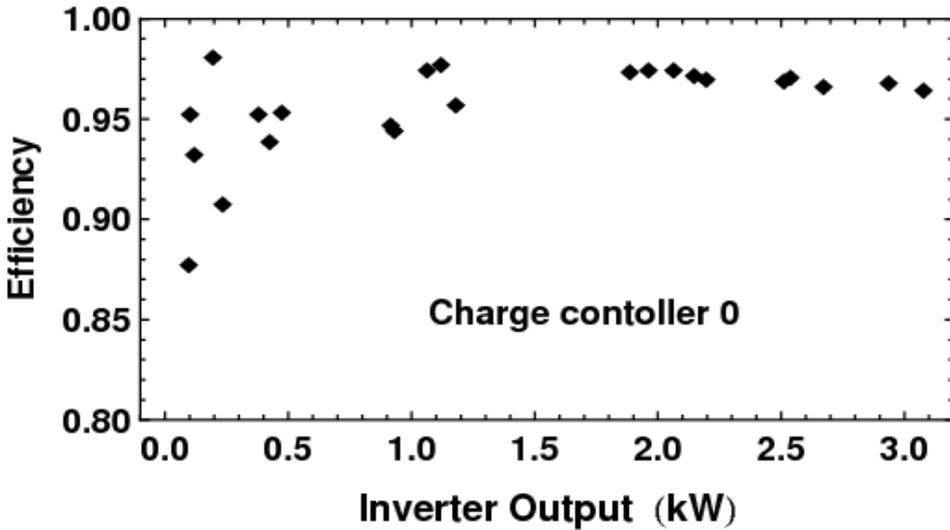
Comparison of daily energy produced by the solar modules (at output of DC to DC converters) compared to AC energy emerging from the inverter



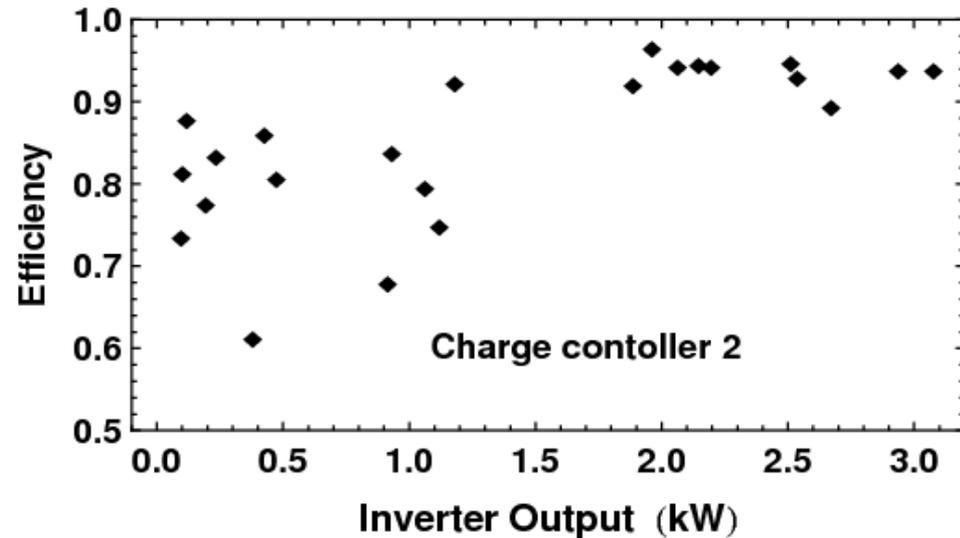
Efficiency of solar energy conversion measured from the output of the DC to DC converters through to the inverter AC output for my grid tie battery system



Charge Controller (DC to DC converter) Efficiencies



A charge controller, also known as a DC to DC converter, transforms the solar module output voltage to the voltage required to charge the battery.



My system of mounting the panels on wooden T beams provides good airflow below the panels, leading to lower panel temperature operation for greater energy output.

