Solar-Assisted Hemodialysis

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Summary

Background and objectives Hemodialysis resource use—especially water and power, smarter processing and reuse of postdialysis waste, and improved eco-sensitive building design, insulation, and space use—all need much closer attention. Regarding power, as supply diminishes and costs rise, alternative power augmentation for dialysis services becomes attractive. The first 12 months of a solar-assisted dialysis program in southeastern Australia is reported.

Design, setting, participants, & measurements A 24-m², 3-kWh rated solar array and inverter—total cost of A$16,219—has solar-assisted the dialysis-related power needs of a four-chair home hemodialysis training service. All array-created, grid-donated power and all grid-drawn power to the four hemodialysis machines and minireverse osmosis plant pairings are separately metered. After the grid-drawn and array-generated kilowatt hours have been billed and reimbursed at their respective commercial rates, financial viability, including capital repayment, can be assessed.

Results From July of 2010 to July of 2011, the four combined equipment pairings used 4166.5 kWh, 9% more than the array-generated 3811.0 kWh. Power consumption at 26.7 c/kWh cost A$1145.79. Array-generated power reimbursements at 23.5 c/kWh were A$895.59. Power costs were, thus, reduced by 76.5%. As new reimbursement rates (60 c/kWh) take effect, system reimbursements will more than double, allowing both free power and potential capital pay down over 7.7 years. With expected array life of ~30 years, free power and an income stream should accrue in the second and third operative decades.

Conclusions Solar-assisted power is feasible and cost-effective. Dialysis services should assess their local solar conditions and determine whether this eco-sensitive power option might suit their circumstance.


Introduction

In hemodialysis (HD), much attention is given to dialysis delivery, maintenance of water quality, monitoring systems, treatment delivery, treatment adequacy profiles, biochemical review, and improvement of patient outcomes. Although these emphases are clearly appropriate, the HD milieu is also undeniably wasteful of basic utilities—water and power—and single-use dialysis consumables—lines, prepacked concentrates, and dialyzers. A vast carbon footprint is left behind.

Little thought has yet been given to the resource demands of dialysis. More efficient resource use and conservation, smarter processing and reuse of postdialysis waste, and even improved eco-sensitive building design, insulation, and use are all fundamental components of what we do—but we do them uniformly badly.

Our dialysis service has critically examined the practical environmental aspects of pre-and postdialysis treatment. Our interest unexpectedly arose as a result of our successful decade-old home nocturnal dialysis program (1), where 35 of 115 HD patients currently successfully self-dialyze at home. Unintended consequences often arise in new programs, and our patients were quick to identify that we had unintentionally transferred the costs for water and power from a facility responsibility to a patient burden.

To correct this oversight, we first addressed dialysis-related water use and introduced reuse practices for reverse osmosis reject water (2–4). Concurrently, researchers from Morocco reported using postdialysis reverse osmosis of the dialyzer effluent to create water suitable for agricultural reuse (5,6). Although thought-provoking, their costs were high, and the additional power demands were significant (7).

In the United Kingdom, the National Health Service has funded a Green Nephrology group (8) to ecosurvey all UK renal units and formulate a green transformation process (9). An exhaustive carbon footprint of renal service delivery and the dialysis process has been generated (10), confirming the extraordinary and disproportionate environmental impact of dialysis (11,12). This impact will compound exponentially as incidence and prevalence of dialysis patients inexorably rise. The European Dialysis and Transplant Nurses Association and European Renal Care Association, copartnered by Fresenius Medical Care Deutschland GmbH, published the first environmental guidelines for dialysis in September of 2011 (13).
Another important ecoinitiative includes more effective management programs for infectious plastic medical waste. Although yet to be adopted, autoclave sterilization and shredding of plastic waste is now possible (14), and the end product—a dried, sterile shreddate—then can potentially be recycled and/or back sold to the plastics industry for reuse in items such as roadwork bollards or plastic hosing.

In addition to water reuse and improved waste management strategies, the per capita power demands of dialysis are huge. Each dialysis treatment uses more than one-half the daily power consumption of an average Australian four-person home. As power prices rise steeply and are predicted to soar to two to three times the current rate over the coming decade in Australia (15,16), the potential for practical, financially viable, renewable power source assistance to energize the dialysis process is increasingly business-case attractive, environmentally sensible, and eco-sensitive.

The two most common alternative power options include solar—both directly grid-donated and reimbursed or directly used after onsite battery storage—and wind power. Solar power has the advantage of silence, consistency, and longevity—the mean life expectancy of current solar arrays being 25–30 years. A solar array links any number of voltage-rated solar panels in parallel to create a calculated surface area sufficient for the calculated power requirements.

Solar exposure is measured by either direct recording of solar radiation or the calculation of solar insolation—the solar radiation energy received on a given surface area in a given time (expressed as W/m² or kWh/m²·d) (17). Interestingly, US data show significantly higher insolation in the south-western United States (17) compared with the populated areas of Australia, including the site of our study in Geelong, a city 75 km southwest of Melbourne, Australia (18).

Although other solar work in dialysis has been reported, this work has been restricted to the use of solar-heated exchange mechanisms to preheat dialysate (19). A second description, by Fresenius Medical Care (Australia) (20), refers to our Geelong project.

This report describes the first full 12-seasonal month outcome data of a pilot program in Geelong (latitude 38° S, mean daily exposure=4.2 kWh/m²). A solar insolation comparison chart for US cities is provided by the National Renewable Energy Laboratory (21); note that Geelong is comparable with St. Louis, Missouri (38° N). US solar insolation can also be Internet-assessed by geographical location (22).

This report describes our first attempt to solar-augment the dialysis power of a four-station home HD training service and forms the first known and reported solar project in dialysis.

Materials and Methods
The home HD training unit (HTU) comprises four HD training chairs. Two to three chairs are used for training new patients for home nocturnal dialysis, whereas the remaining one to two chairs provide for retraining, problem solving, or respite care.

Although training is accorded to demand, commonly, two to three patients train concurrently on Mondays, Tuesdays, Thursdays, and Fridays for ~5 hours each day (20 h/wk). Once trained, patients transfer to the home.

Each of the four home dialysis equipment combinations comprise a Fresenius 4008B single-pass dialysis machine [Fresenius Medical Care (Australia), North Sydney, Australia] that is water-supplied by an individual piggy-back Aquuno reverse osmosis (RO) system [Fresenius Medical Care (Australia), North Sydney, Australia].

To determine the mean total power draw, we first separately metered and serially measured the independent draws of each dialysis machine plus RO pairing. The mean weekly expected power draw and power generation capacity can be estimated by knowing (1) the expected range of power use per equipment pair (in our feasibility study, each machine and RO pairing consumed a mean of 1.289 kWh/operating h per pair); (2) the average weekly hours of operation in the four-station HTU (this number must include the predialysis run-up, prime phase, and postdialysis rinse and sterilize phase); and (3) the mean expected annual regional solar exposure (daily, weekly, monthly, and annual tables are available for any worldwide geographical coordinates from regional meteorological services or on the Internet) (14).

A range of commercially available solar arrays, insolation-rated by their weekly expected kilowatt per hour generation capacity, can be matched against the weekly expected dialysis service power requirements. A 24-m², 3-kWh-rated Conergy P175 solar array and Conergy Inverter system (Conergy Australia, Malaga, Western Australia, Australia) was chosen.

To facilitate simple assessment, the HTU was rewired, segregating the four-machine/RO pairs and isolating their electrical circuits from all other electrical power draws in the building. This separation permitted the exact power draw of only the dialysis-specific electrical equipment to be metered and recorded. Concurrently, the power generated by the solar array is metered and recorded at the inverter before being directed to the national grid. This simplified meter system has permitted weekly tracking of all grid-donated power and power drawn specifically for dialysis-related use.

Minute counters in the machine and RO systems record machine and RO operating times.

Results
The solar-assisted HTU project commenced full operation on July 26, 2010. For this report, data were censored at 12 months (July 25, 2011) to acquire a full 12-month seasonal dataset. The program is ongoing.

From a “what has the weather been like” assessment, the 12-month study period was one of the worst remembered. However, solar exposure is not entirely sunshine/sunlight-dependent, and it can differ significantly from the impression of an observer. Figure 1 shows the Geelong mean daily global solar exposure (23) expressed in megajoules per meter² as a monthly mean for the study period (black bars). This finding is compared with the historical data for the two preceding decades (1990–2011) for the same months (gray bars). The mean average solar exposure for Geelong is 15 MJ/m² or 4.2 kWh/m² (23), and the solar exposure for the study period showed a higher than
average exposure, despite high recorded rainfall and cloud cover for the period.

Table 1 shows the full 12-month solar study data. Note that, although the unit operates for home training on only 4 d/wk, occasional home respite or other chair use has occurred on several weekly fifth days throughout the 12-month study period. The days of operation are, therefore, recorded as 208+ days to recognize these additional days of operation.

Equipment use for the all Fresenius 4008B HD machines was ~64 h/wk (16 h/machine per wk). The Aquuno RO systems averaged 75 h/wk (19 h/RO per wk). The total kilowatt hours used by each pair was 4166.5 kWh, ~9% greater than the 3811.0-kWh array-generated power contributed to the grid.

Because our 23.4-m² array generated a mean 73.2 kWh/wk and one paired HD/RO system used ~16 h/wk consumes ~20 kWh/wk, a 6.4-m² array would be required at our geographical location to generate sufficient power for one paired HD/RO system. A patient dialyzing for a total of 12 h/wk would require an ~15 kWh equivalent to a 4.8-m² solar array.

The total cost for the array, inclusive of solar consultant fees, purchase of the array and inverter, installation, unit rewiring and metering, and electrical inspection fees—discounted to wholesale as a hospital-related installation—was A$16,219. No subsequent maintenance costs are anticipated. At the time of this study, the amount being reimbursed by the power utility for grid-donated power was 23.5 c/kWh. For the same period, the amount charged for grid-drawn power was 26.7 c/kWh. The 12-month cost of power billed to the HTU service was A$1145.79. The reimbursement to the unit equaled the array-donated power×23.5 c/kWh = A$895.59, yielding an effective power cost reduction of 76.5%.

A newly announced solar-incentivizing rate for grid-donated power (60 c/kWh from October 1, 2011) would, using current data, increase the effective reimbursement to $A2286.60. If power-drawn costs remain stable, an annualized income stream of A$1140.90 (A$2286.60 in and A $1145.70 out) should result. If these relative price differentials hold, all power costs would be negated, whereas the return on investment against the total capital cost (A$16,219) would reduce from ~18 years (A$16,219/A$895.59) to 7.7 years (1 year at A$16,219 – A$859.59=A$15,323+6.7 years at A $15,232/A$2286). With an estimated array lifespan of ~30 years, a long-term, cost-free power source has been potentially secured as free power, and an income stream accrues.

**Table 1. Solar-Assisted Dialysis Program—Key Data Points**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days of data collection</td>
<td>365</td>
</tr>
<tr>
<td>Days of operation</td>
<td>208+</td>
</tr>
<tr>
<td>Total training treatments delivered</td>
<td>402</td>
</tr>
<tr>
<td>Total active treatment time per treatment (hours)</td>
<td>5.5</td>
</tr>
<tr>
<td>Combined machine hours</td>
<td>3345.2</td>
</tr>
<tr>
<td>Combined RO hours</td>
<td>3919.2</td>
</tr>
<tr>
<td>Total kWh used (HD machines + RO systems)</td>
<td>4166.5</td>
</tr>
<tr>
<td>Mean total kWh used per operating day</td>
<td>20.03</td>
</tr>
<tr>
<td>Total kWh created by the solar array</td>
<td>3811.00</td>
</tr>
<tr>
<td>Effective kWh created per operating day</td>
<td>18.32</td>
</tr>
<tr>
<td>Power bill (at 26.7 c/kWh) without solar assist ($A)</td>
<td>1145.79</td>
</tr>
<tr>
<td>Power bill (at 26.7 c/kWh) with solar assist ($A)</td>
<td>269.26</td>
</tr>
</tbody>
</table>

RO, reverse osmosis; kWh, kilowatt hours; HD, hemodialysis; c, Australian cent; A$, Australian dollar.

**Discussion**

Encouraged by the concerns of our home HD patients to lessen the costs of dialysis utilities, we embarked on several resource conservation initiatives. The first of these initiatives addressed water reuse practices and RO reject water recycling. We successfully developed several practical interventions that have led to reductions in water losses of up to 100,000 L/wk over our combined facility and home HD sites. These initiatives have previously been reported (2–4). A natural progression for our conservation interests, thus, moved from water to power.
Debate around carbon generation and the best ways to lessen the individual, institutional, and national carbon footprint is currently a primary focus of the Australian political agenda. It was therefore timely to consider the carbon impact of dialysis systems and explore ways by which to lessen this impact.

Most Australians do not currently support the introduction of nuclear power, and it seems unlikely that this national view will change in the foreseeable future. In addition, Australia is ideally placed—with its vast area and abundant exposure to sun, wind, and ocean—to develop and install alternative power sources. Wind power remains contentious, marred by claims of noise and visual pollution. Wave power technology remains rudimentary. Solar power is clearly the most likely alternative to develop and flourish. Furthermore, solar array efficiencies improve year by year.

We determined to test the potential for solar-assisted HD, choosing solar above wind power, because solar radiation is silent and as it penetrates cloud, more dependable. Wind is noisy and unpredictable.

We chose the simplest solar model: array donation to and service draw from the national grid. Although remote dialysis might well require a battery and store system—a model already in use by many remote and isolated solar installations—these systems are far more expensive, requiring large, costly battery bank support. Although potentially justifiable in remote locations, a donate and draw option was the best fit for our urban service.

Because home-based dialysis is being actively encouraged in Australia—the clinical outcomes are reportedly better and the costs are significantly lower (1)—incentive programs at both state and federal levels have been designed to encourage both home HD and peritoneal dialysis uptake. Although we chose to first assess solar potential at our facility HTU, where systems could be assessed and evaluated with greater ease, the longer-term aim is to assess whether installation of home solar power—as a further incentive to the options already offered to our home patients for RO reject water reuse—is feasible.

In the United States, where home HD is more commonly a short daily HD regimen (6×2–2.5 h) using the NxStage system with a power consumption significantly less than single-pass machine and RO systems in use in Australia (10), it is likely that a significantly smaller, cheaper array would produce adequate dialysis-related power. However, if home solar installation were to be considered for Australian home HD programs where patients dialyze for 28–40 h/wk (3.5–5×8 h), up to 50 kWh/wk would be required, creating a far more challenging funding equation.

A cost-benefit analysis of any additional added costs to those costs already implicit in home installation of dialysis equipment must weigh the costs of purchase and installation against the possibility of early transplantation or unexpected death. Partial payment or repayment contracts are possible solutions if the added costs of solar installation begin to approach or exceed the financial savings that accrue against center-based dialysis from a robust home program.

Although clearly, this concept remains a distant goal, this small pilot study has already shown us that solar-assisted dialysis is neither particularly difficult to design and install nor prohibitively expensive.

Indeed, our current system is already providing most of the power requirements for four conventional single-pass machine and RO pairs. Although admittedly, these systems only operate for one 5-hour session 4 d/wk, this process has been achieved at almost no net power consumption after subtracting equipment power use from array power generation. Importantly, the current system and billing/reimbursement ratio also approaches cost neutrality. If the recent reimbursement rate changes persist—changes that were introduced to encourage greater home solar uptake—the current system will turn a profit for the service in addition to generating effectively free power.

Charges for grid-provided power and reimbursement rates for grid-donated power from alternative sources such as solar or wind will vary from place to place and power company to power company. Thus, decisions can only be made about financial viability with local knowledge of these factors. In addition, solar exposure varies depending on the geographical location. However, because solar exposure does not necessarily equate to or depend entirely on sun exposure, many may be surprised to find significant solar exposure at their home location, despite the apparent lack of a hot sun weather pattern.

We would encourage the dialysis community to assess the solar exposure records at their home geographical position. These exposure levels can be simply and quickly determined using the Internet (24). After providing local latitude and longitude coordinates, tables and graphs can be obtained for the mean daily, weekly, monthly, or annual solar exposure. Knowing the expected local solar exposure, available solar arrays, local purchase and installation costs, power rates charged by local utilities, any predicted price changes, and local reimbursement rates for grid-contributed power, a simple calculation can determine whether solar-assisted power might be financially viable. Affordability also needs to be considered in the light of the expected increases in power costs now predicted worldwide for the coming years and decades.

There are many limitations to this early study. Although solar radiation varies widely by season, year, and global geographic location, making forward radiation predictions inexact, regional meteorology service charts still permit a reasonable estimation. Solar-assisted dialysis will be clearly more financially justifiable for some services than others, because the variability of solar exposure and the vagaries of billing and reimbursement schemes dictate applicability. These issues and others are beyond the control of dialysis services. In addition, because we chose to apply this project at our HTU, an area dependent on home training and home respite demand, machine and RO usages were both less predictable and less regularly demanding compared with a fully operational maintenance dialysis facility.

We believe that all Australian HD services should perform a simple mathematical calculation to assess the applicability of solar-assisted power for their dialysis unit(s). Furthermore, similar assessments should be made in the light of local circumstance, wherever dialysis is delivered.

Ecodialysis—previously described by these authors as green dialysis—should be a natural consideration for any dialysis service. Although not all locations, purchasing environments, or local administrations will be suitable or supportive, the twin issues of environmental degradation and
climate change demand that simple ecoassessment is made and solutions sought. The added potentials for water conservation and improved waste management systems using steam sterilization of postdialysis plastic waste before shredding and on-selling for reuse manufacture as well as other ecodialysis programs demand attention and thought.

For too long, we have (ab)used but have not considered the environmental consequences of that (ab)use. It is time to change that paradigm. This small step opens the door to that change. More need to step through the door.

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Disclosures
None.

References

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