

PURSUING BEST COST SOLAR CONCENTRATION

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ABSTRACT

Solar concentrating systems offer the hope of being the most cost-effective method of capturing and utilizing solar energy, but the fact remains that traditional combustion-based generation of thermal and electrical energy is still considerably less expensive for the typical industrial user. Government incentives help to close this cost gap, as will future cap and trade markets for the CO₂ and other greenhouse gases resulting from competing combustion processes. Large solar developers base their business models strongly on the leverage provided by these incentives, but most small to medium sized industrial companies still make decisions regarding electrical and thermal energy needs based on simple return on investment calculations. The recent recession has brought this home, as companies are compelled to select the most economical thermal and electrical power generation possible in order to survive. The public relations advantages of “being green” are difficult to justify for the typical industrial user in these tough economic times.

This paper discusses one method of closing the cost gap between traditional and solar power generation- achieving best cost concentration of solar energy through the use of film-based reflective materials incorporated into a point focus concentrating dish design with sun tracking capability.

The cost advantages of reflective films are considerable in comparison to traditional mirrors using glass substrates (thick or thin), and film production also leaves a significantly lower carbon footprint. Point focus implementation offers lower radiant thermal losses compared to line focus/ trough-based systems.

A lightweight yet strong dish design enables a very low mass for the tracking structure to move, and a weathervaning stowage mode protects the dishes from high wind and hail events.

The ability to dynamically adjust focal length on the dishes offers flexibility in implementation, and also provides the

ability to quickly return dishes to a safe unfocused condition in the event that tracking control is lost.

Reflective film or “stretched membrane” reflectors have been well-studied in the past as a method of concentrating solar energy. This paper will discuss the problems experienced designing focusing systems utilizing reflective films, and cover the author’s latest improvements.

An operational ¼ scale model of a 4-dish system with tracking apparatus will be discussed, along with thermal and survival testing of this unit in heavy wind conditions.

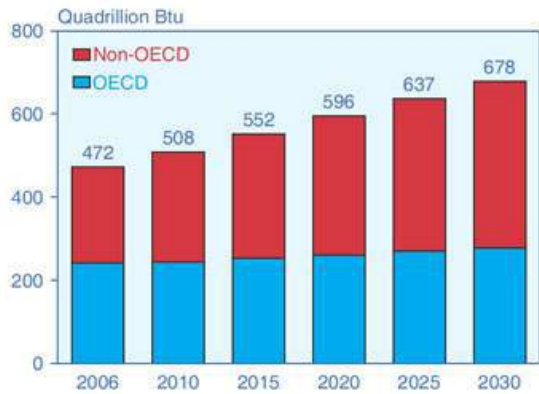
The resulting concentrating solar system is configured as a “dish/thermal” system, with two possible thermal receiver arrangements. One design will contain an integral receiver mounted to the tracking frame which will maintain direct on-axis orientation to the reflected radiation from the sun. Another design is for a stationary receiver mounted to a small scalable power tower, fed by multiple focusing tracking structures.

In summary, this paper will discuss an important, yet rarely discussed problem with solar energy- the continued high substitution cost for solar energy over traditional combustion-based generation. One method of lowering the delivered cost of concentrated solar energy will be discussed, with test results presented for a concentrating dish design utilizing durable reflective film, and mounted to a lightweight tracking structure. Survival testing in high winds will be presented. A thermal receiver design integral to the tracking structure will be discussed, as well as a single receiver mounted to a mini-tower.

1. PROBLEM

World energy consumption is expected to increase significantly as populations continue to grow, and as developing nations improve their infrastructures.

Figure 1. World Marketed Energy Consumption, 2006-2030



Sources: **2006:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, *World Energy Projections Plus* (2009).

Fig. 1- Projected Worldwide Energy Consumption.

Renewable energy is projected to supply an increasing percentage our energy needs as the cost of traditional fossil based energy production increases and the body of evidence predicting climate change grows. Historical data suggests that past projections have been optimistic, however, and that contribution by renewables has been flat over the past several decades.

Figure 1: Non-fossil energy use grows rapidly, but fossil fuels still provide 78 percent of total energy use in 2035

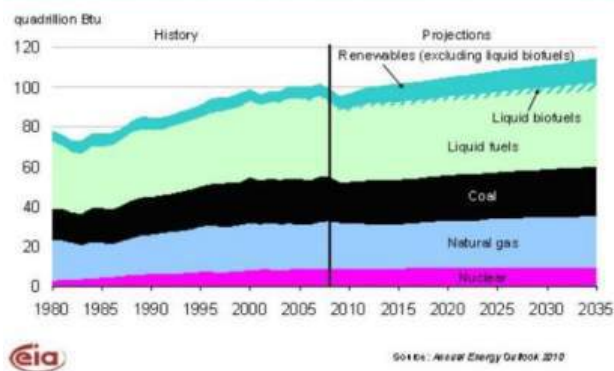


Fig. 2- Historical and projected energy production by source. US Energy Information Administration- 2009.

Finally, consider that most of renewable generation relies on, hydropower, biofuels, and wind.

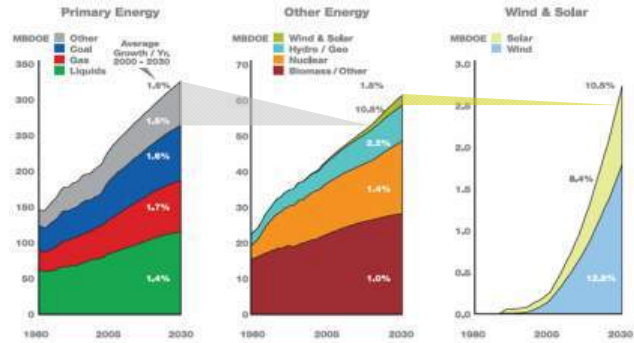


Figure 3- Solar Energy as a percentage of total forecasted energy. Source: “The Outlook for Energy”, ExxonMobil 2006

The fact remains that traditional fossil-based energy production remains significantly less expensive than renewable energy production, including solar energy. This was summarized in the 2009 EIA “World Energy Projections”.

“ Except for those two sources (Wind and Hydro), most renewable energy technologies are not economically competitive with fossil fuels over the projection period, outside a limited number of niche markets. Solar power, for instance, typically is uneconomical but can be economical where electricity prices are high and government incentives are available. In fact, government incentives or policies typically provide the primary support for construction of any renewable generation facilities.”¹

Government incentives will continue to help to close this cost gap, as will future cap and trade markets for the CO₂ and other greenhouse gases resulting from competing combustion processes. Large solar developers base their business models strongly on the leverage provided by these incentives, but most small to medium sized industrial companies still make decisions regarding electrical and thermal energy needs based on simple return on investment calculations.

The recent recession has brought this home, as companies are compelled to select the most economical power generation possible in order to survive. The public relations advantages of “being green” are difficult to justify for the typical industrial user in these tough economic times.

2. ONE APPROACH

A Better Focus Co. is a small manufacturer of solar dishes, and dedicated to improving the cost effectiveness of solar

energy production. The dish design that will be discussed utilizes reflective film stretched across a round dish that has a sealed shallow cavity inside. When a vacuum is pulled inside the dish, the film deforms into a concave shape that focuses sunlight to a concentrated spot. Small (45") dishes have been manufactured since 2005 for cooking applications, and scaling to an 8' diameter size has been successful, with three prototypes produced and tested. *-



Figure 4- 4' diameter cooking dish (left) and 8' diameter power dish (right).

The first patents for solar dishes utilizing vacuum-deformed reflective films were issued in the 1960's², and the design has been well studied. Problems with past designs include poor durability of reflective films, poor focusing accuracy, poor thermal stability in changing weather conditions, and heavy sun-tracking structures that constitute a high percentage of the system manufacturing cost. A past paper discusses the author's approach to addressing each of these problems³, summarized as follows:

- Film Durability- New reflective films offer better durability than in the past⁴, with a predicted life of at least 10 years.
- Design implementation of reflective film into a vacuum-formed dish creates wrinkling of film⁵. These wrinkling issues are addressed with the author's design, as well as thermal stability issues in changing weather conditions.
- Manufacturing cost of between \$24-57/sq.M has been demonstrated.
- Specific design embodiments to address the above have resulted in the allowance of US Pat. # 7374301.

3. NEW WORK

Recent research efforts have focused on three areas:

- Improving focusing accuracy
- Developing a lightweight and cost-effective sun-tracking structure.
- Weatherability and survival in high winds.
- Receiver arrangements- dish/thermal vs scalable tower.

3.1 Focusing Accuracy

Smaller focal points provide less radiant losses at the receiver, particularly when there is wind that can sweep away heat from receiving surfaces. A parabolic shape yields an ideal focal point, but vacuum-deformed film results in a more spherical shape, and a larger concentrated spot. Earlier work with floating battens to inhibit film wrinkling has also found application in reducing the size of the focal point. This and other film characterization techniques have improved concentrations on the 4' diameter dishes from 130 suns to over 600 suns (calculated as dish aperture divided by focal point diameter)

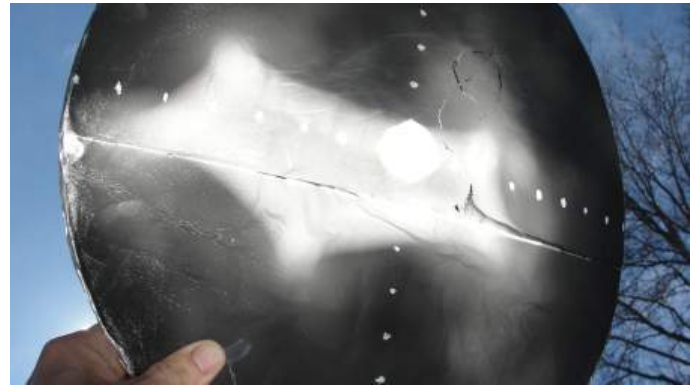


Figure 5- Focal point from an uncharacterized 4' diameter dish at a 12' focal length



Figure 6- Characterized 4' dish at a 12' focal length.

Characterized film also has the ability to maintain a good focus spot at longer focal lengths.

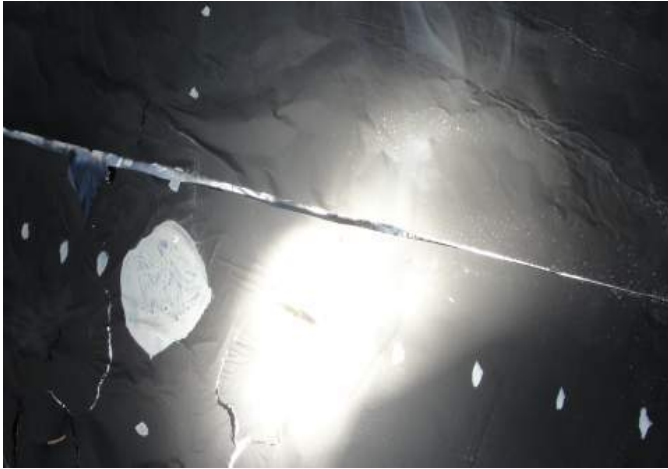


Figure 7- Characterized dish at a focal length of 25'.

3.2 Tracking structure

The envisioned tracking structure would carry 4 10' diameter dishes, each developing app. 5 kw. of thermal power at optimum on-axis orientation to the sun. Each dish will concentrate to a common optimum focal point of between 6" and 12" diameter.

A ¼ scale model of this sun-tracking structure has been built and tested. This model utilizes a monolithic pole, with a PVC frame to hold 4 dishes. The dishes utilize three adjustable mounting points. The top two points utilize hinges that permit the dishes to flip upwards during high wind conditions in a weathervaning stowage mode.



Figure 8- ¼ scale model carrying 4 dishes

It should be noted that although this model is operational for thermal testing purposes, it has not been automated with a processor or drives for sun-tracking.



Figure 9- Another view of ¼ scale model.



Figure 10- 4-dish tracking structure, configured as a dish/thermal system with integral receiver. (insulated receiver plate depicted.).



Figure 11- 4 dishes focused onto a thermocouple on insulated thermal receiver plate.

Ambient wind conditions have been light in the past year, so a vehicle was used for high wind testing.



Figure 13 - 1/4 scale model mounted for high wind survival testing.

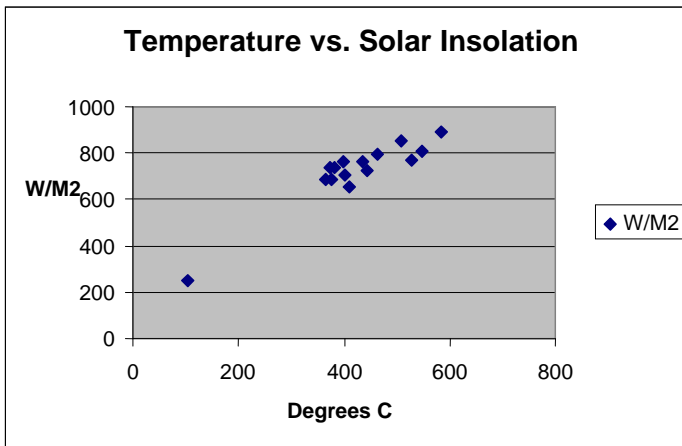


Figure 12- Heat generated vs. sun intensity.

3.3 Weatherability

Several aspects of weatherability should be considered: UV resistance- Accelerated life testing at NREL has estimated at least a 10 year life on the Reflectech Solar film⁴. This film has seen actual service on trough systems for 6 years, with little degradation.

Wind events- lightweight dishes enable lightweight tracking structures, but large surfaces are still being presented to the wind. The design solution selected is to implement a passive weathervaning mode in winds above 25 mph. The tracking structure will turn it's back to the wind, protecting the reflective surfaces from blowing sand or hail. Additionally, the dishes are mounted to hinges, permitting them to flip upwards, reducing the total surface area incident to the wind by greater than 50%.



Figure 14 - Tracking structure at 30 mph.



Figure 15 - Tracking structure at 50 mph. Note that film on the dishes are slightly pressurized to establish a safe convex shape, and also to prevent destructive rippling of the film.

Individual deflectors mounted to the frame just upwind of the dishes redirects wind from the top of the dish, where it would inhibit rotation, to the bottom of the dish, where rotation is enhanced.



Figure 16- Wind deflector redirects oncoming wind downward, assisting upward rotation.

Cold weather operation- the ¼ scale model has survived heavy snow events without damage.



Figure 17- Carrying a snow load after a winter storm.



Figure 18- Cold weather operation

Operation in cold weather is enhanced by solar thermal tensioning that keeps the film stretched tightly³

3.4 Manufacturing cost

Dish material cost for 4' diameter cooking dishes averages \$25-30 per M².



Figure 19- Pre-shipment dish testing

These dishes are constructed utilizing reflective mylar, have poor UV resistance, and are intended to be brought indoors after use.

The 8' diameter power dishes have been constructed with Reflectech Solar film, and total materials cost has been \$57/ M².

Both sets of material cost have the potential of significant cost reduction with higher quantity purchases.

There is app. 21% material wastage in constructing the round dish from rectangular sheets coming off of the rolls that the reflective material is shipped on. However, the 4 waste corners from a large dish can be combined to make 2 small cooking dishes, leaving the wastage at a more reasonable 3%.

Dish construction is currently labor-intensive, but is suitable for automation with powered rotary fixtures.

3.5 Receiver Arrangements

Past point-focus dish systems have frequently been configured as dish/engine systems, with integral Sterling engines for generating electricity. The 1/4 scale model depicted is configured as a dish/thermal system, for generating high temperature hot water, steam, or for heating a heat exchange fluid. Although initial testing has been conducted with receiver integral to the tracking structure, the variable focusing capability of the reflective film dishes enables a scalable power tower, with a stationary receiver mounted at the top. Multiple tracking structures each carrying dishes with different focal lengths can be arrayed beneath a common tower. Individual trackers would not have to endure the weight or cost of integral receivers. Capacity factor is enhanced as multiple trackers are easily added.



Figure 20- 8' diameter dish at 18' focal length



Figure 21- 8' diameter dish focal length adjusted to 37 feet, slightly off-axis to the sun.



Figure 22- Off-axis by 45 degrees.. The focal spot becomes a focal line.

Each of these two receiver arrangements has it's own advantages and disadvantages.

Integral Receiver Advantages:

Always operates on- axis to the sun

Integral Receiver Disadvantages:

- Requires a receiver for each tracker.
- Adds significant weight and moment.
- Requires complex rotary seals to move water or other heat exchange fluids though the receiver.

Scalable Tower Advantages:

- Trackers are much lower cost and weight
- Single stationary receiver on top of a small tower.
- Low complexity to move fluids

Scalability- trackers may be added over time. Good capacity factor.

Scalable Tower Disadvantages:

- Operates off-axis most of the time
- Initial high cost to build tower

4. SUMMARY

Solar energy does not currently constitute an economic substitute for traditional combustion-based generation. Reflective film offers one potential of significantly reducing the cost of delivered solar energy. A lightweight reflective film enables a lightweight concentrating dish design, thus enabling less expensive tracking structures. Lightweight dishes and tracking structures still present a large surface area to high wind events, so a weathervane mode of stowage during high wind events permits lightweight components to survive high winds.

A vacuum-formed dish offers the unique capability of dynamically varying the focal length of the dishes so that a safe flat mirror configuration can quickly be established in the event that sun-tracking control is lost. Dynamic focal control also enables a scalable power tower design, fed by multiple focusing trackers below.

Note that evolution of the use of polymer materials on the exterior of automobiles has experienced many setbacks, but the underlying economies provided a constant pull for continued development, and has resulted in higher and higher % levels of polymer content. A similar pull for achieving best-cost concentration of solar energy is present, and polymeric reflective materials will likely play a part in solar concentration in the future.

A Better Focus Co. is seeking a user/partner to build the first full-scale 4-dish tracker for generating steam or hot water. Intellectual property jointly developed will be shared.

5. REFERENCES

- (1) United States Energy Information Administration 2009 report on World Energy Projections Plus
- (2) Kopitko (US pat. 3031928, 1962)
- (3) A Lightweight Concentrating Solar Dish Design Utilizing a Stretched Membrane Reflector. Doug Simmers. ASES 2008.
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- (5) Finite Element Analysis of Thin Membrane Wrinkling. 2003. Johan Mansson & Johan Soderqvist- Royal Institute of Technology , Sockholm, Sweden.