2012

Energy storage for renewable energy

Saugato Mukerji

University of Wollongong

Energy storage for renewable energy

Abstract

Presented at All Energy Australia 2012 International Conference, Melbourne

Disciplines

Engineering | Science and Technology Studies

Energy Storage for Renewable Energy

The biggest remaining challenge

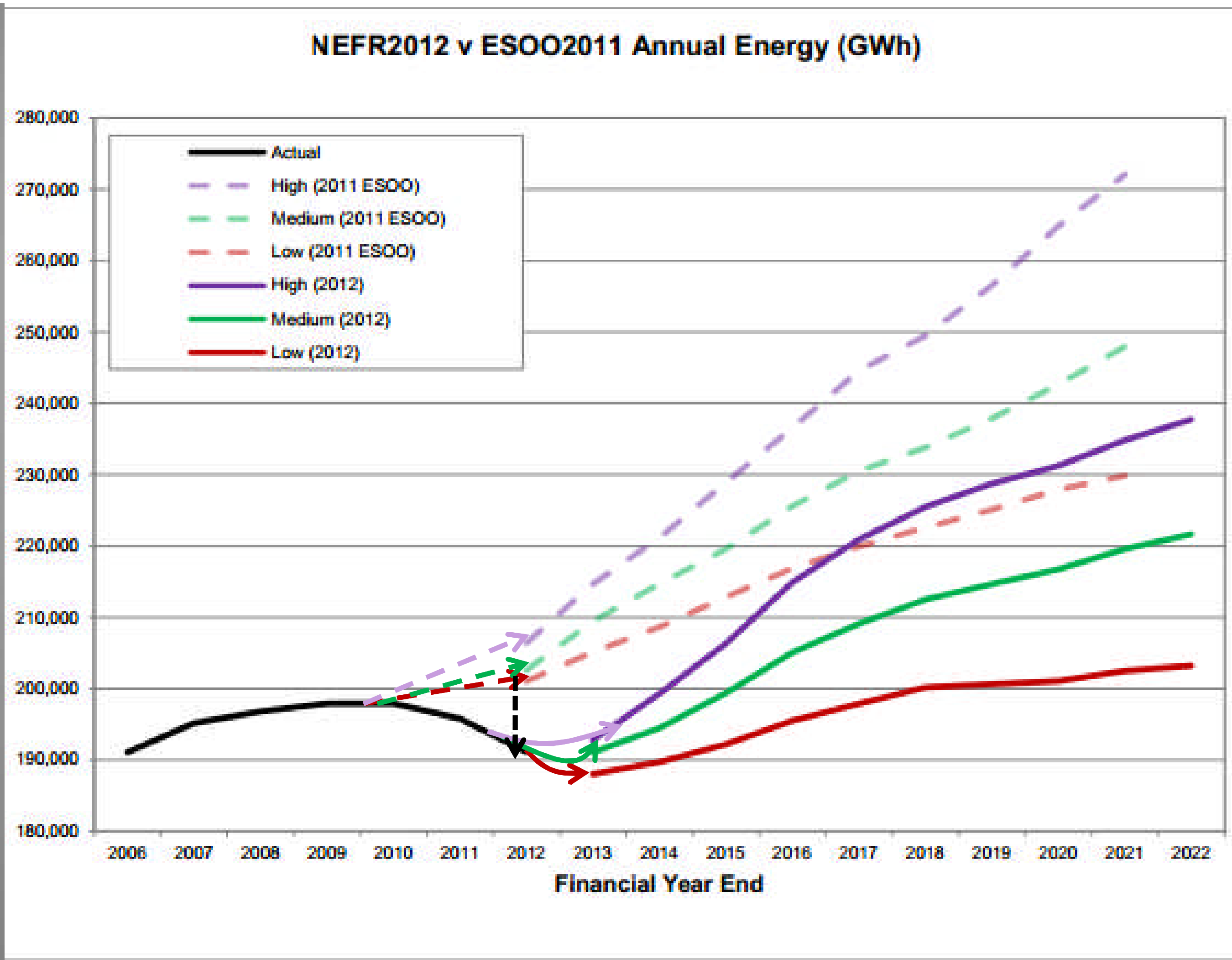
Saugato Mukerji

Layout

- Built environment has potential to increase its renewable energy usage massively and become energy positive over 24hrs and the cost incentives to drive this change are approaching critical mass.
- This will completely change where and when and how energy is used, generated, stored, transported and delivered to users.
- This presentation starts at the grass roots and examines the issues & the potential game changers innovations and synergies between them for a RE based future.

Power Demand has dropped or is rising slower

- The belief was the demand would resume pre GFC growth by 2011
- This did not happen
- Power Demand in Australia had dropped by 5% from predicted values in 2011-2012



"Across the NEM, annual energy for 2011-12 is forecast to be 5.7 per cent lower than estimated in the 2011 Electricity Statement of Opportunities (ESOO) under a medium economic growth scenario

Key NEM investment drivers in 2012 involve the following:

- AEMO's latest energy and maximum demand projections have fallen considerably since 2011.
- Small-scale generation investment has increased rapidly over the last three years.
- The Large-scale Renewable Energy Target (LRET) is driving continued investment in wind generation capacity.
- Average spot market prices have been falling in every region since 2007–08

Drop was due to

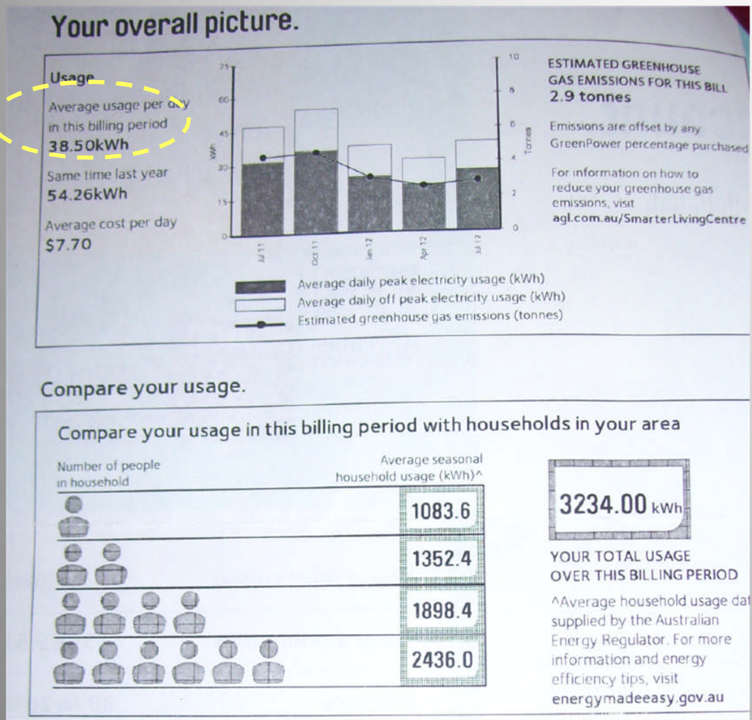
wind, rooftop solar new installed capacity and voluntary demand management

- Commissioning of wind farms taking capacity from 817MW in 2007 to 2005MW in 2011
- Solar PV installation driven by great FITariffs
- Switch to gas or solar water heating.
- Lower industry demand for electricity.
- Endurance of a bit more hardship by using the reverse cycle air conditioning more frugally.

Drop was due to ...continued

- Switch to aerated low flow shower heads to reduce hot water usage.
- Keeping doors and windows closed when using heating or air conditioning.
- Education about better practices from TV print and internet has helped
- Installing insulation to reduce energy use in air-conditioning.
- Replacement of electric fan heater by more efficient oil/ceramic/gas room heaters
- Driven by NABERS,commercial building owners are making improvements to energy use to get better rents & sale price

RE Opportunities in a Power Bill



Your overall picture.

Usage

Average usage per day in this billing period
38.50kWh

Same time last year
54.26kWh

Average cost per day
$7.70

ESTIMATED GREENHOUSE GAS EMISSIONS FOR THIS BILL
2.9 tonnes

Emissions are offset by any GreenPower percentage purchased

For information on how to reduce your greenhouse gas emissions, visit agl.com.au/SmarterLivingCentre

Average daily peak electricity usage (kWh)
Average daily off peak electricity usage (kWh)
Estimated greenhouse gas emissions (tonnes)

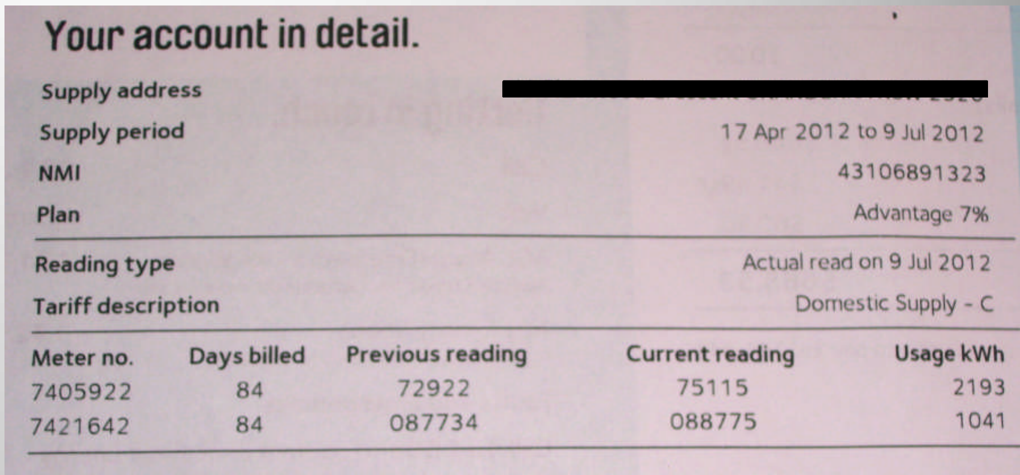
Compare your usage.

Compare your usage in this billing period with households in your area

Number of people in household	Average seasonal household usage (kWh)^
1	1083.6
2	1352.4
4	1898.4
6	2436.0

3234.00 kWh
YOUR TOTAL USAGE OVER THIS BILLING PERIOD

^Average household usage dat supplied by the Australian Energy Regulator. For more information and energy efficiency tips, visit energymadeeasy.gov.au



Your account in detail.

Supply address	[redacted]
Supply period	17 Apr 2012 to 9 Jul 2012
NMI	43106891323
Plan	Advantage 7%
Reading type	Actual read on 9 Jul 2012
Tariff description	Domestic Supply - C

Meter no.	Days billed	Previous reading	Current reading	Usage kWh
7405922	84	72922	75115	2193
7421642	84	087734	088775	1041

The 1041kwh in 84 days for off-peak water heating is a very visible target for solar heating.

This works out to 12.4 Kwh/day for hot water.

Breaking down the rest exposes more targets

Identifying parts of demand that can be deferred

Non water heating load = 2193 / 84 = 26.1 kwh/day

Normal power excluding hot water is 2193 kwh in 84 days which works out to	26.1	kwh/day
TV	2.4	
3 computers 100W x 8hrs/day	3.0	
lighting	2.9	Renewable target
hvac (reverse cycle)	8.5	17.9
room heater	4.6	
2 fridges	4.8	
==		
Power use excluding hot water	26.1	

- The green parts can be deferred to utilise peaks in solar PV or concentrated solar heating
- So total potential for solar driven heating & cooling is
  = 12.4(hot water) +
  17.9(heating, cooling, fridge)
  = 30.3 out of the 38.5 kwh /day total load

The latest quote for the same home is $3500 p.a. Based on this bill using an online estimating tool.

Suddenly serious investment in solar to move bulk of energy use off grid is starting to look reasonable

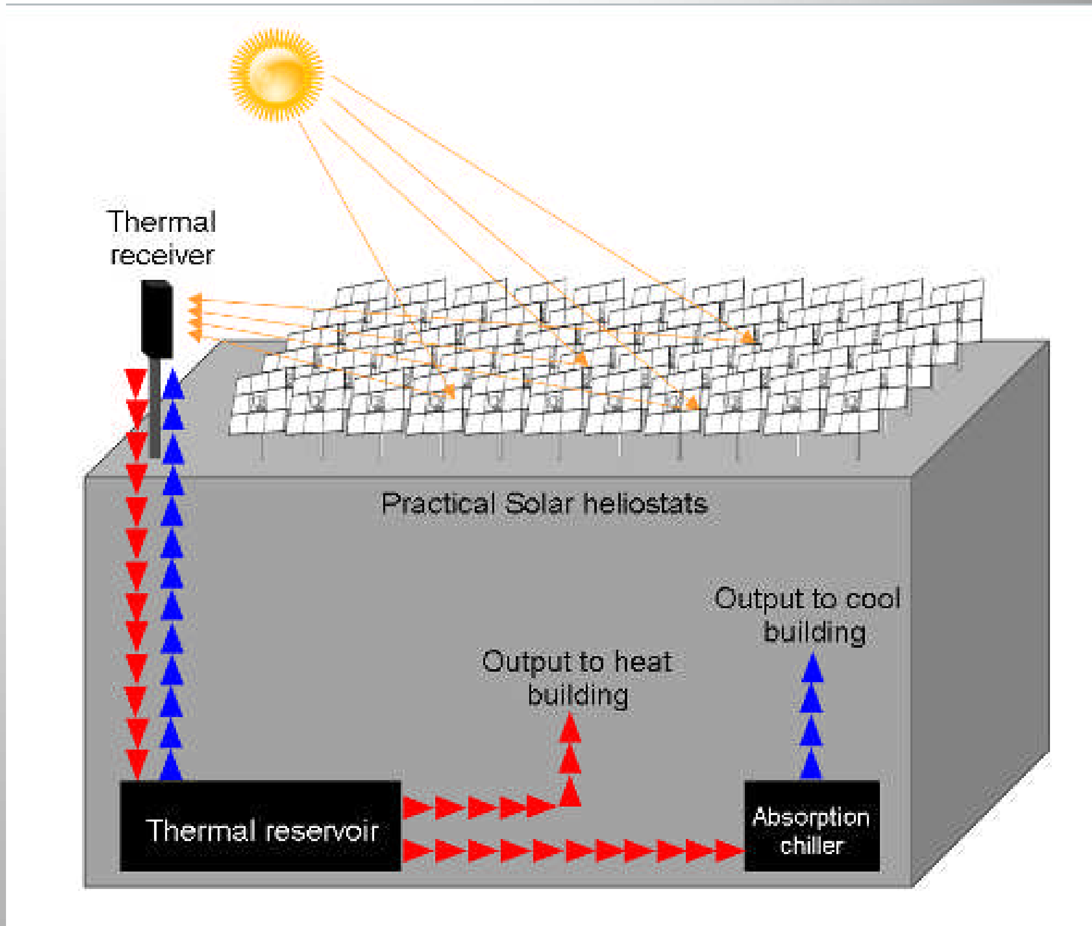
Heating and cooling over 24hrs using conc solar heat saved in a reservoir

Using solar energy for building heating and cooling and hot water is already viable for large office blocks and apartment complexes.

A company called practical solar does this commercially in the US.

The challenge is to do this on a small scale for solar equip in homes & bldgs in Aust & globally

The concept is actually viable at a penetration level of 10% of homes as the economies of scale kick in.



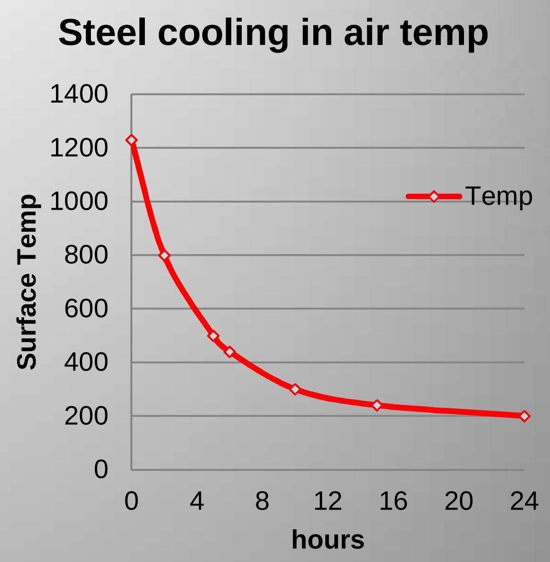
Storing heat in heavy material – may become structural feature in new houses

The exponential temperature decay of steel or rocks with high iron content could be a useful way of storing Heat resulting from CSP at the home level. This could also provide ongoing air/water heating as needed by running pipes into the insulated chamber with the hot steel block.

Steel Heat Store			Haematite Heat store	
billing period in days	82			
water heating load	1047			
water heating load kwh per day	12.77			
equiv KJ/day	45936			
specific heat of steel in KJ/Kg C	0.49		specific heat of haematite in KJ/Kg C	0.78
mass of steel in kgs at 420 C to store this	234.4		mass of steel in kgs at 420 C to store this	147.2
density kg/m3	7850		density kg/m3	5090
cube size in m	0.311		cube size in m	0.307
slab of 0.23m x 1m x	0.130		slab of 0.23m x 1m x	0.126

Air storage of a 23cm thick steel slab offers 16hrs heat storage between 400 & 200 C

Storing the hot block in a insulated chamber with inner walls Painted silver greatly slows the cooling rate



Tracked Solar for 30.4kwh /day

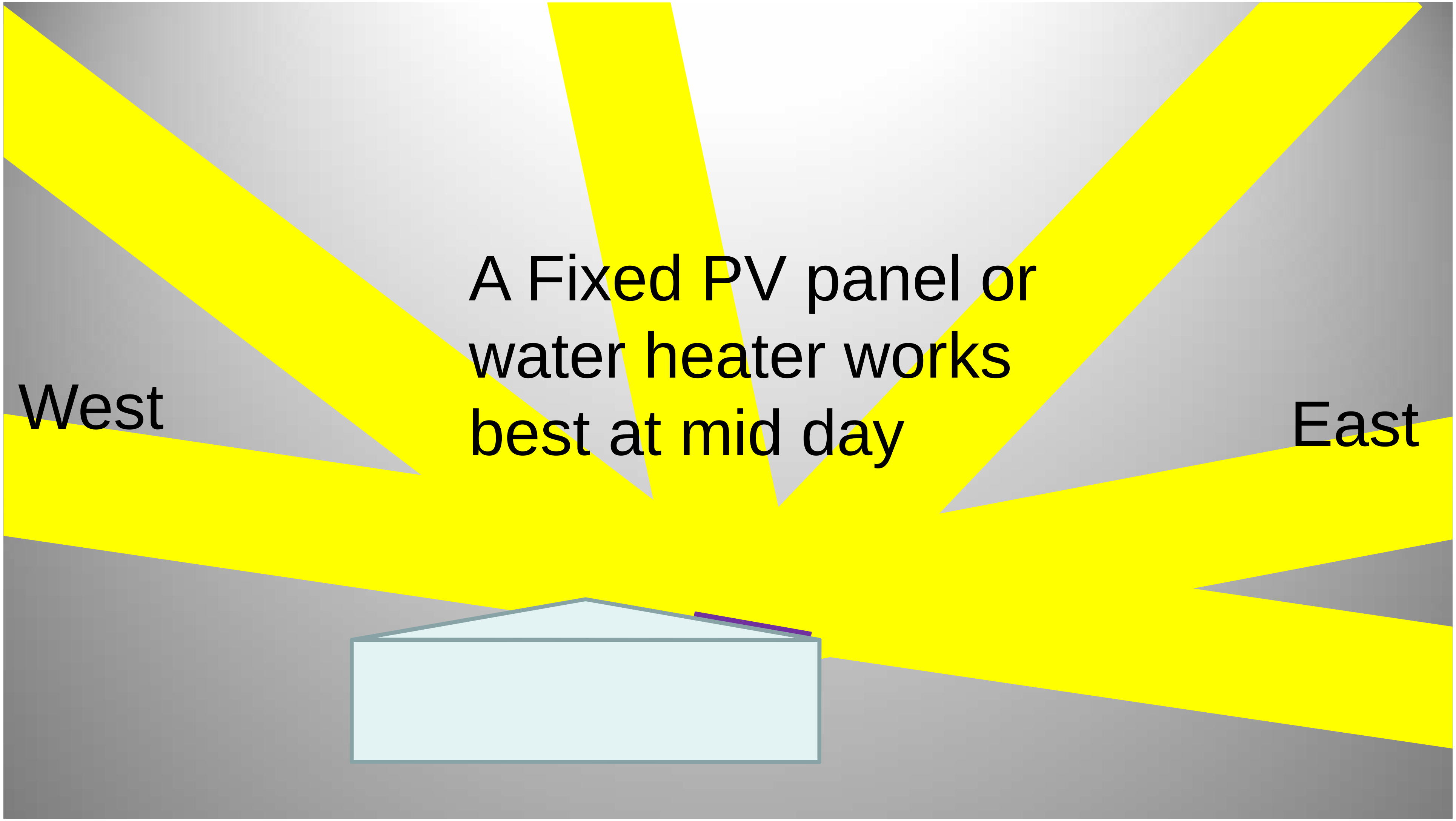
Solar energy on a clear day is 1kw/m^2 or 1kwh/hr/m^2

A heliostat adjusts the mirror angle to makes sure the heat receiver gets the full 1kw/m^2 as the sun moves from E to W

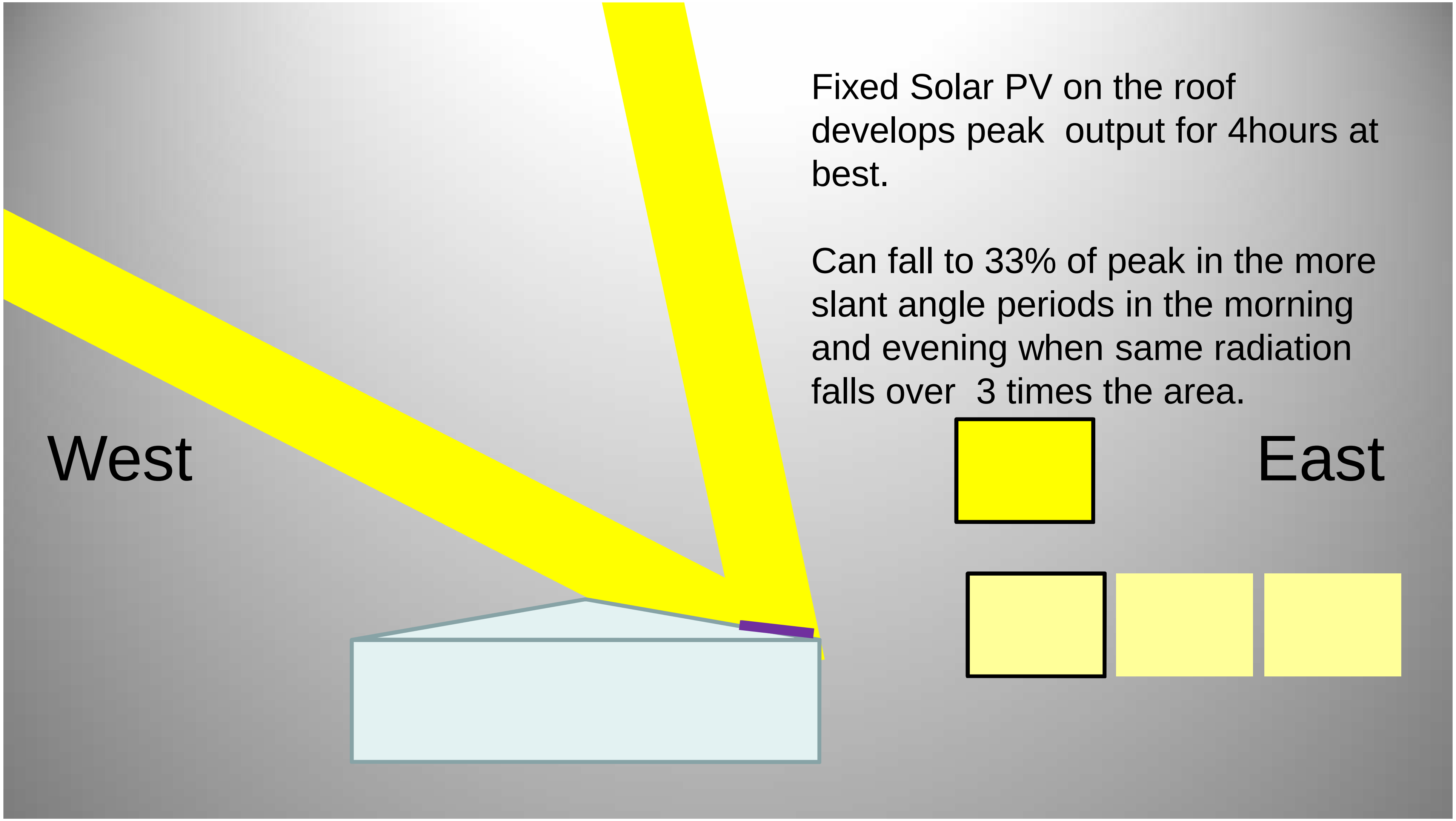
Assuming 8hr of available sunshine it will take two heliostats with mirror area of 2m^2 to deliver the required 30.4kwh/day

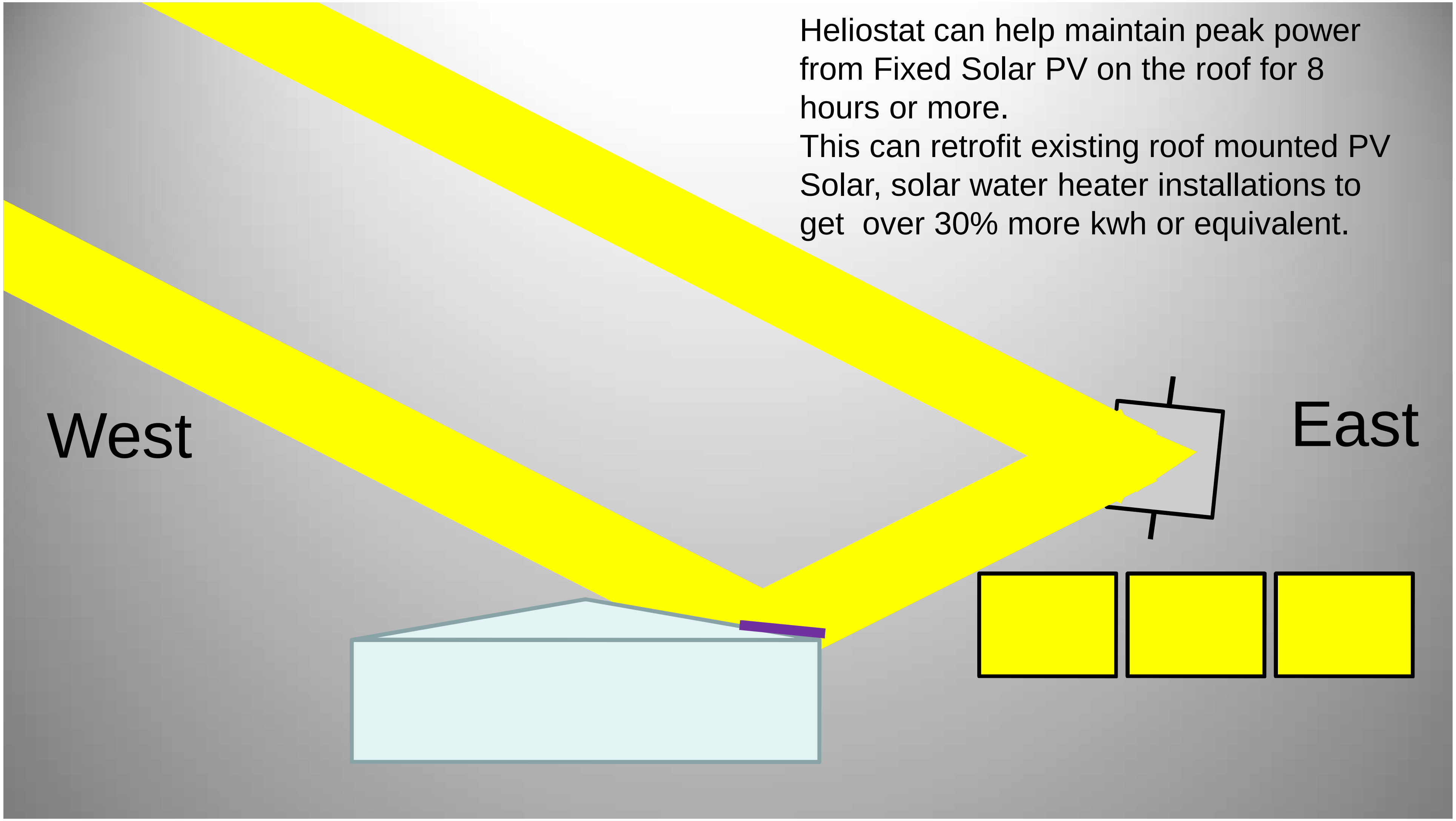
The additional complexity is similar to having hardware for ducted a/c and hot water systems in the garage.

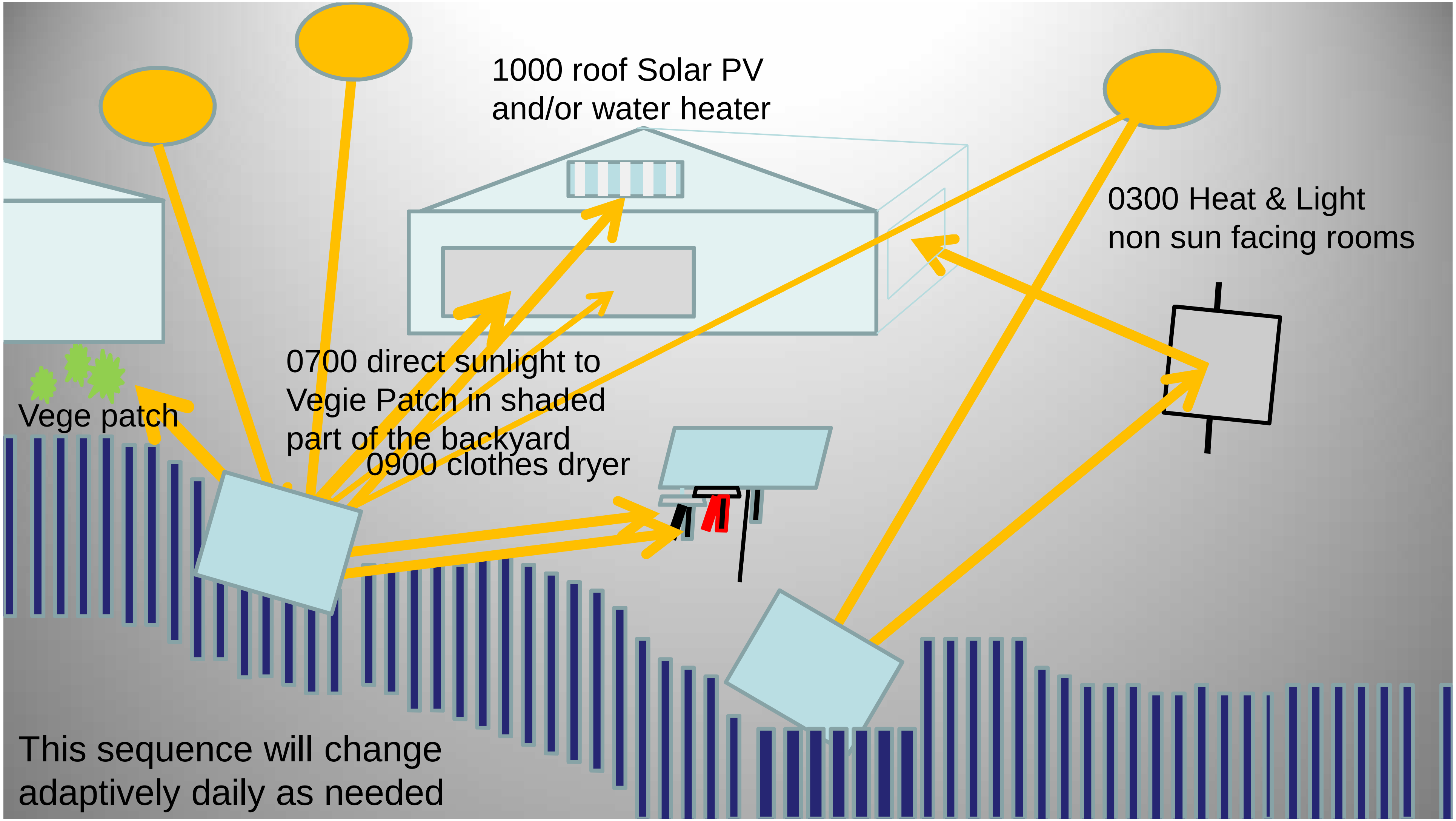
The annual mortgage repayment is $1287. (assuming a $15000 at 7% p.a investment, to take 30.4kwh/day off grid with a equipment life of 25years.), The $15000 is a target project cost, which the equipment suppliers must work to.



A Fixed PV panel or
water heater works
best at mid day
West
East


Fixed Solar PV on the roof develops peak output for 4hours at best.
Can fall to 33% of peak in the more slant angle periods in the morning and evening when same radiation falls over 3 times the area.
West
East


Heliostat can help maintain peak power from Fixed Solar PV on the roof for 8 hours or more.
This can retrofit existing roof mounted PV Solar, solar water heater installations to get over 30% more kwh or equivalent.
West
East


1000 roof Solar PV
and/or water heater
0300 Heat & Light
non sun facing rooms
0700 direct sunlight to
Vegie Patch in shaded
part of the backyard
Vege patch
0900 clothes dryer
This sequence will change
adaptively daily as needed

Cost Incentives for RE are in place now

Diesel genset beats current Peak rate

A 9.5kw diesel genset burns 2L/hr ($3/hr)
Cost = 31.6c/kwh

Diesel genset is already cheaper than the peak tariffs

Solar Feedin Tariff for new PV installations around 6c/kwh in NSW and varies with the retailer and offer.

ELECTRICITY

NSW RESIDENTIAL Energy Price Fact Sheet (Effective 1 July 2012)

Standing Offer

AusGrid (Formerly Energy Australia) Distribution Zone

origin

The offer set out in this Energy Price Fact Sheet is only available to customers in the relevant distribution area with the necessary metering system/configuration. Your charges for the sale and supply of electricity are listed below.

Domestic	Unit	Excl GST	Inc GST
Consumption of first 1,000 kWh/qtr	c/kWh	24.40	26.840
Consumption of next 1,000 kWh/qtr	c/kWh	25.50	28.050
Remaining consumption kWh/qtr	c/kWh	34.30	37.730
Daily Supply Charge	c/Day	62.80	69.080
Domestic TOU (Powersmart)	**Unit**	**Excl GST**	**Inc GST**
Peak consumption (2pm - 8pm EST on Weekdays)	c/kWh	47.77	52.547
Shoulder consumption (7am-2pm and 8pm-10pm Weekdays and 7am-10pm EST on weekends and public holidays)	c/kWh	19.40	21.340
Off peak consumption - All Other Times	c/kWh	11.90	13.090
Daily Supply Charge	c/Day	74.70	82.170
Controlled Load	**Unit**	**Excl GST**	**Inc GST**
All controlled load 1 consumption	c/kWh	10.10	11.110
All controlled load 2 consumption	c/kWh	13.30	14.630

Demand Management to avoid peak rates

- As the rollout of smart metering and the associated differential tariffs for peak, shoulder and off peak is implemented. Ability to have hot water, HVAC systems that preferably work off the cheaper offpeak and then the shoulder periods provides dollar savings.
- Direct capture of thermal energy in a reservoir of hot water, hot rocks or steel from concentrated solar using heliostats is the most efficient way to harness solar.

•This heat can be preserved with very little loss by suitably insulating the heat reservoir.

- Concentrated solar has one major benefit in that it can store the heat at higher temperatures in hot rocks, steel slabs. This heat can then be slowly released as required by blowing air or circulating water, oil or even direct conduction though metal slabs or bars from the heat reservoir to the target area or appliance.
- Cooling can be obtained from the stored heat using an absorption chiller

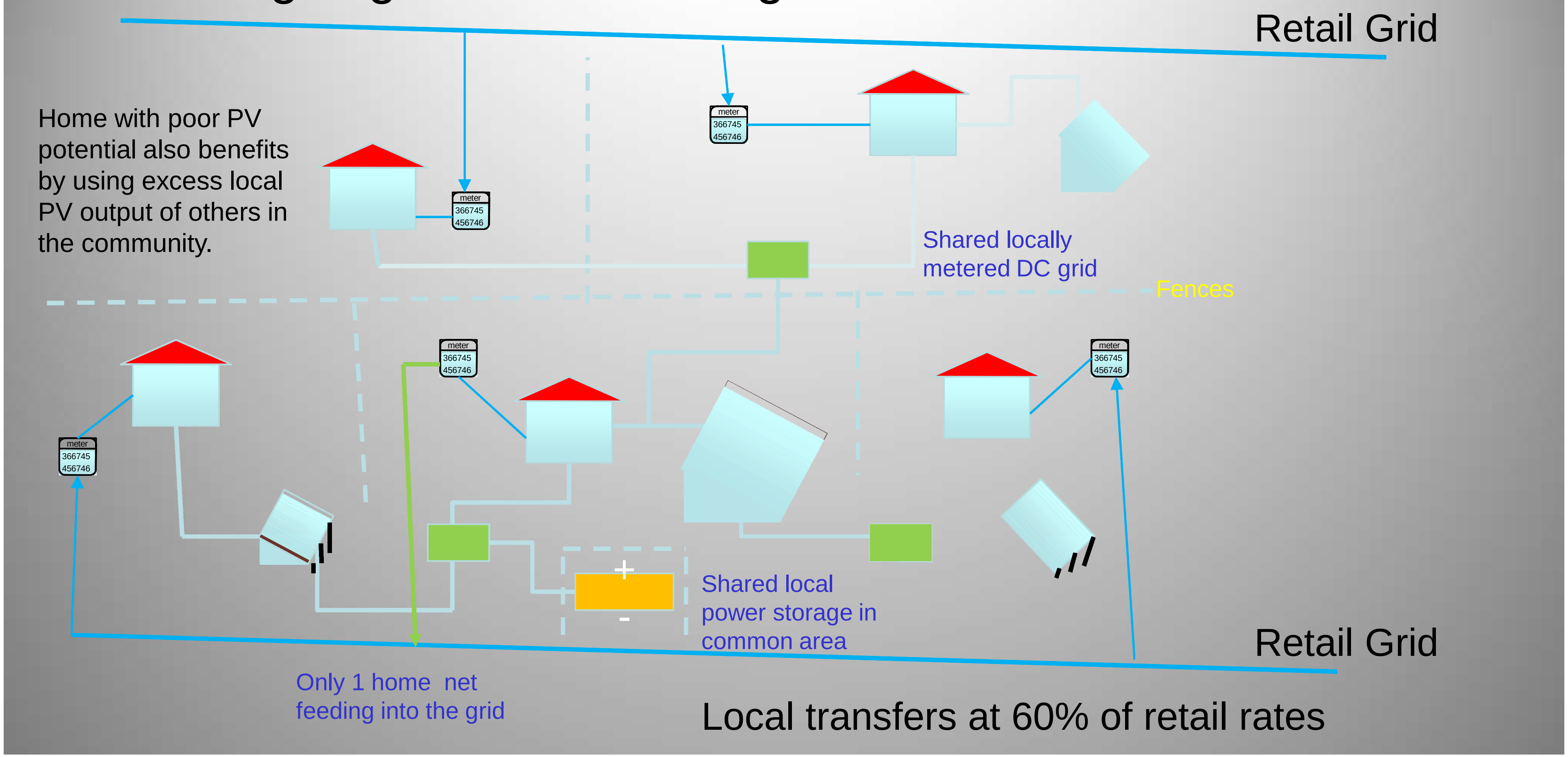
A solar PV friendly fridge and airconditioning

- **fridge only works 30% of the time & cuts out on achieving the temp target**
- A solar friendly fridge would have a large onboard freeze pack like we use to treat sprained ankles.
- The fridge would run non stop during peak solar PV hours & freeze the freeze pack solid.
- The freeze pack would melt slowly in the evening night and early morning to provide cooling.
- A single 220w solar panel may be able to run a 400litres fridge on most days.
- A backup AC power connection could provide security on cloudy days or days of extreme hot weather or where the fridge door is opened often.
- Needless to say the same concept will work very well in a solar powered off grid eco home or camp site.
- The same concept can be expanded to include further chilling air already pre cooled with non contact evaporative cooling. Imagine a water feature fountain whose purpose is beyond aesthetics.

PV is already viable at retail tariff rates

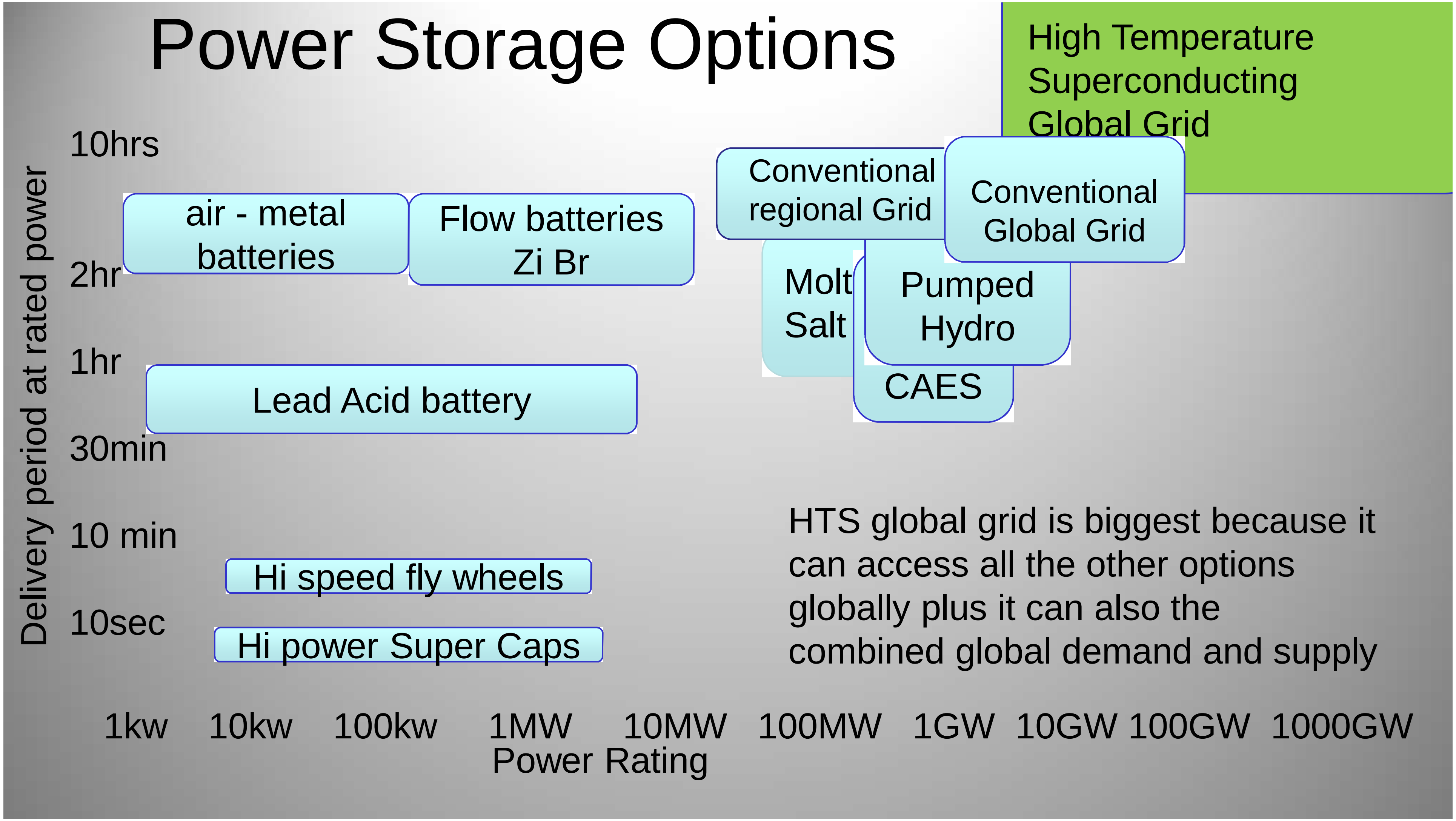
- PV is already viable at retail tariff rates if the entire PV output can be consumed.
- Current appliances and residential loads not smart enough or not designed to to shift demand to align with peak PV output.
- Power retail companies in NSW are offering 6-8c per kwh as feedin tariff when charging 34-38c per kwh as power tariff
- Residents are already forming solar communities to obtain better prices by bulking their PV panel and equipment purchases.
- To get max benefit for their PV investment, adjacent neighbours could form PV power sharing solar communities and keep more of the surplus within the community and only export the collective net excess power to the grid.
- The net intra community flows can be settled at 60% of the retail rates giving benefit to the supplier as well as user. A shared battery or other power storage facility can yield further savings instead of selling power at 6c/kwh to the retailer.

Solar Communities may run parallel DC local grids with only net PV going to the retailers grid



Potential for energy storage as a service

- In the medium term, as storage technologies advance, retail and wholesale power customers will demand the right to store their excess renewable energy with commercial energy storage utilities for a price based on amount & number of hours.
- The same customer would then expect to draw down their stored energy from the storage utility, at times of peak or shoulder pricing to derive the maximum benefit. It is understood the storage process will have some losses i.e. 5% to 25%
- The retail energy supplier who operates the distribution network can charge a usage based fee, for transferring the power from the customer location to the storage utility and back. Auto tap-changing distribution will be needed to support this.
- The retail energy supplier may itself decide to also provide the storage service once the volume becomes commercially attractive.
- When majority of power consumers start using energy store as a service to store energy building energy storage capacity becomes impractical.
- At this point a truly global scale energy store solution is needed



Power Storage Options
High Temperature Superconducting Global Grid
10hrs
2hr
1hr
30min
10 min
10sec
Delivery period at rated power
air - metal batteries
Flow batteries Zi Br
Conventional regional Grid
Conventional Global Grid
Molt Salt
Pumped Hydro
CAES
Lead Acid battery
Hi speed fly wheels
Hi power Super Caps
HTS global grid is biggest because it can access all the other options globally plus it can also the combined global demand and supply
1kw
10kw
100kw
1MW
10MW
100MW
1GW
10GW
100GW
1000GW
Power Rating

In 2007 a Global Grid was proposed

The idea was to connect the regional grids into a global grid by building the relatively small missing segments between the grids.

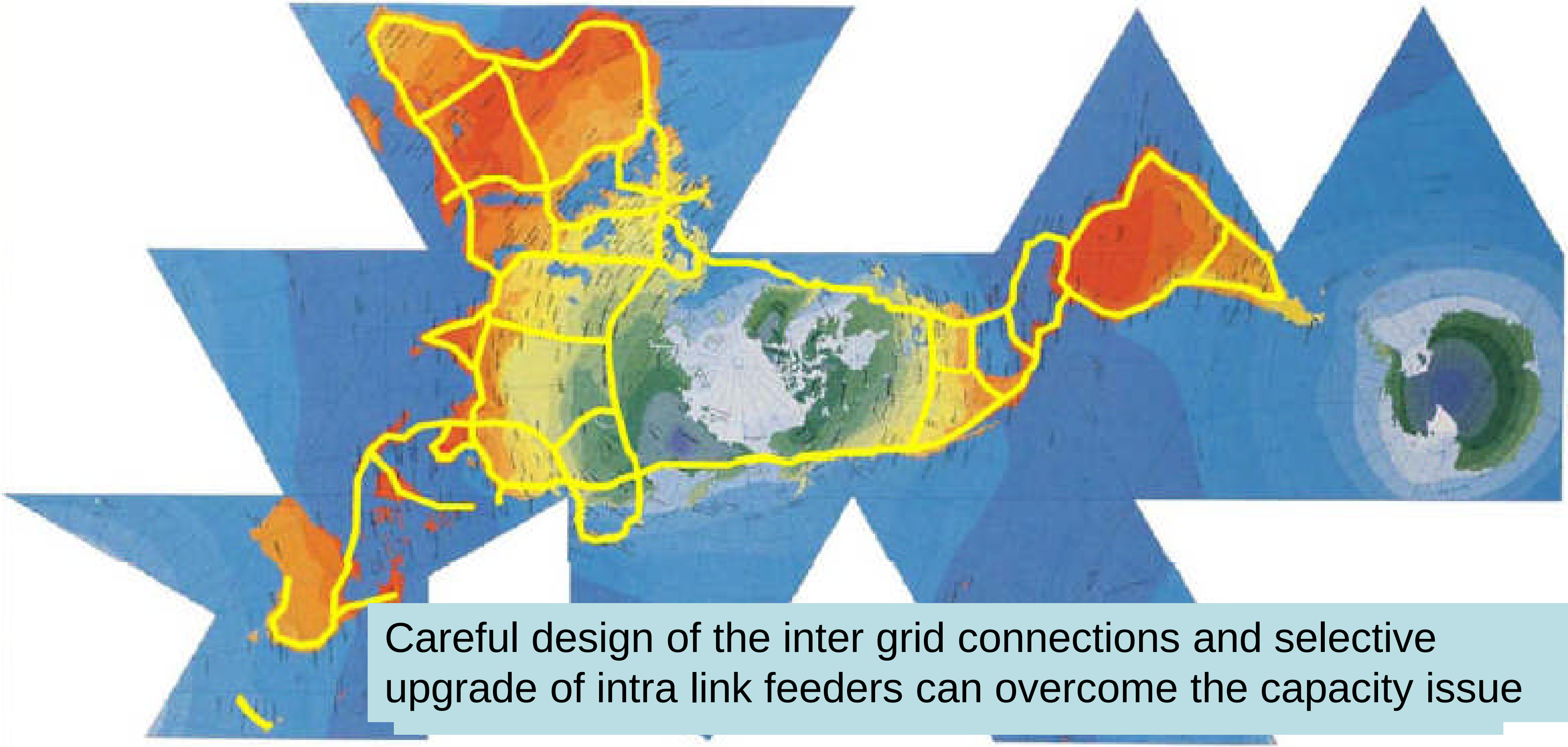
To create a global network on which the sun never sets

The concept involves utilising the installed investment in power generation for common good in a spirit of global cooperation matching peak demand in one location with low demand at a different time zone over the global grid.

The concept has a lot of merit in exploiting the full potential of renewables like wind and PV which can be highly volatile in their output and dispatchability.

Emerging Global Energy Network

Regional electricity grids that can form a worldwide energy network



Careful design of the inter grid connections and selective upgrade of intra link feeders can overcome the capacity issue

Global Grid Benefits

The idea was to connect the regional grids into a global grid by building the missing segments between the grids.

The benefits Included:

- A Peak demand in one part of the global grid was matched with an unutilised excess capacity in another part.
- Excess renewable capacity that could not be stored is not lost (i.e. Freewheeling windmills) but was used elsewhere on global grid giving revenue to the source.
- The full utilisation of global renewable capacity meant the additional renewable utilisation would displace equivalent fossil fuel burning generation.
- This has huge GHG reduction potential in the order 5-10% of power related GHG emissions by preferentially utilising the most efficient generators of power.
- The amount of additional fossil fuel based capacity needed to meet projected peak demand would reduce, as the global grid helped meet peak demand using excess energy availability from other areas of the globe.

Global grid is more relevant as the share of renewables rises

Renewables by definition are less predictable and have high variability

Wind power can go from a peak to a low value in 15min. There can be peaks and troughs as wind direction and velocity changes

Solar power too can have similar swings in power output as full or partial cloud cover interfere with the availability of sunshine in the target area. Sandstorms and dust haze too can restrict output.

Renewables also exhibit a seasonal variability. Wind is stronger in some parts of the year and solar is definitely more productive in summer on a sunny day because

- The hours of sunshine are more
- The sun is lower in the sky hence makes a larger angle ϴ with the vertical.

A large number of storage technologies are being developed targetting different energy storage scenarios. A global grid potentially out performs all others in most criteria except cost . Reducing the cost in $/MW/km is the development challenge.

Enabled by a global grid energy would become another globally traded commodity

- The global grid can operate like a big wholesale market where farmers offer their produce for sale and big traders buy different quantities from a number of different sellers to create the supply chain flow they need.

- The good or poor production in an individual farm, district. Has a limited impact on the price of a commodity like wheat since an opposite variation at other districts may average out the variation in supply of the commodity if the transport infrastructure is good enough to move the commodity to where it is needed.

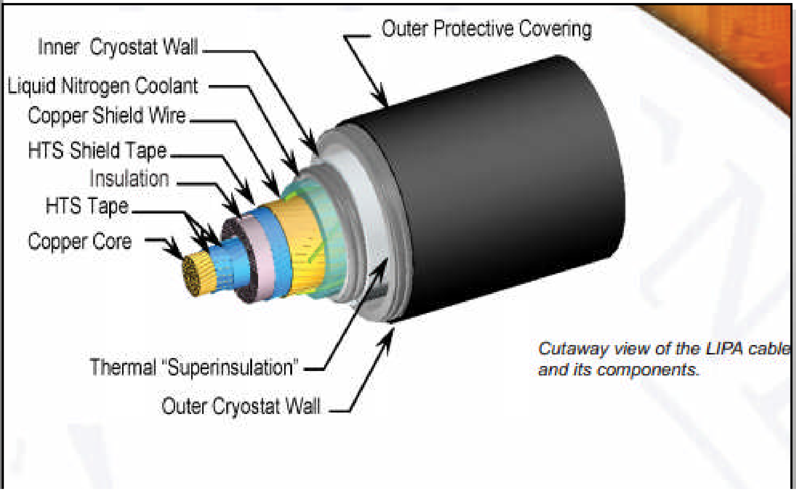
HTSuperconducting Transmission Lines

- Superconductivity of metals in liquid helium was discovered over 100 yrs ago. The resistance of a solid mercury wire fell to zero below 4.2K .
- In superconducting materials, the characteristics of superconductivity appear when the temperature T is lowered below a critical temperature Tc.
- The highest critical temperature found for a conventional superconductor is 39 K for magnesium diboride (MgB2)
- Cuprate superconductors can have much higher critical temperatures: YBa2Cu3O7, one of the first cuprate superconductors to be discovered, has a critical temperature of 92 K
- Boiling Point of Nitrogen is : 77.36 K (-195.79˚ C). So immersing YBCO in liquid nitrogen causes superconductivity.
- So surrounding a YBCO core with liquid nitrogen in a sealed insulated tube called a cryostat creates a superconducting transmission line.

State of Play in HTS transmission lines

HTS transmission lines[26]

Location	Length (km)	Voltage (kV)	Capacity (GW)	Date
Carrollton, Georgia				2000
Albany, New York[27]	0.35	34.5	0.048	2006
Long Island[28]	0.6	130	0.574	2008
Tres Amigas			5	proposed 2013
Manhattan: Project Hydra				proposed 2014
Essen, Germany[29]	1	10	0.04	proposed



Cutaway view of the LIPA cable and its components.

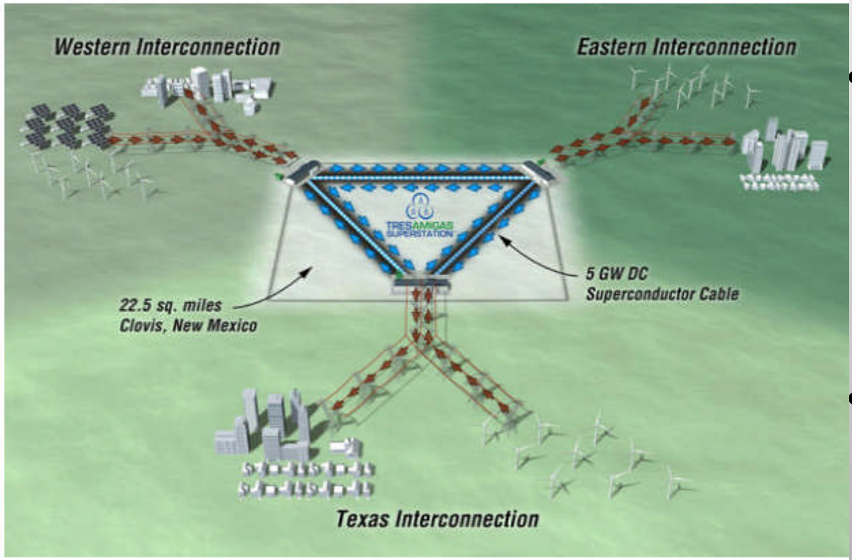
What is the status of the Long island project?

The cable was energized April 22, 2008 and serves the equivalent of 300,000 homes. It is the first HTS power cable to operate at transmission voltage in the grid. LIPA plans to retain the superconductor as a permanent part of it's grid. The line carries 4100A at 138kV to deliver 0.574GW.

Tres Amigas Project

to build the Tres Amigas "SuperStation" to link the three power grids of the US and create the nation's first renewable energy market hub

BY ARIEL SCHWARTZ | OCTOBER 14, 2009



Sure, installing solar and wind power is easy enough, but it's difficult to transport alternative energy from its sources--usually rural locations--to the cities that need it. That's where the Tres Amigas Project, announced today by New Mexico governor Bill Richardson, comes in.

- Each arm of the triangular grid is rated for 5GW
- Previously the Eastern Grid, Western Grid and Texan Grid have been separate, preventing cheap electricity being sold from one end of America to the other.
- The superstation is also designed to link renewable solar and wind power in the grids, and is to use HTS wire from American Superconductor. "Some 23 years after its invention, today HTS comes of age. "

So what needs to happen with HTS

Needs to become significantly cheaper than HVDC using more common materials

Needs to become more robust and easy to install harder to damage

Needs to become manufacturable on a massive scale for global rollouts

The current leader is a relatively small high tech company with less than $500m turnover.

A Large power transmission equipment vendors needs to back HTS risking the existing HVDC offering

My reading HTS is where the jet engine was in 1945. It took 20 years to become the mainstream....

US NREL says 80% Renewable possible in 2050

The june 2012 plan includes solar, wind, hydro, pumped and other storage.

The plan has a security focus seeks to make contiguous US energy independent

Assesses a variety of scenarios with prescribed levels of renewable electricity generation in 2050, from 30% to 90%, with a focus on 80% (with nearly 50% from variable wind and solar photovoltaic generation);

identifies the characteristics of a U.S. electricity system that would be needed to accommodate such levels; and describes some of the associated challenges and implications of realizing such a future.

increased electric system flexibility, needed to enable electricity supply-demand balance with high levels of renewable generation, can come from a portfolio of supply- and demand-side options, including flexible conventional generation, grid storage, new transmission, more responsive loads, and changes in power system operations.

Existing technologies are used with some assumption of improvement

A central idea is when the sun goes down the wind blows harder so there is a compensatory effect.

80% Renewable by 2050 relies heavily on wind, biomass. solar

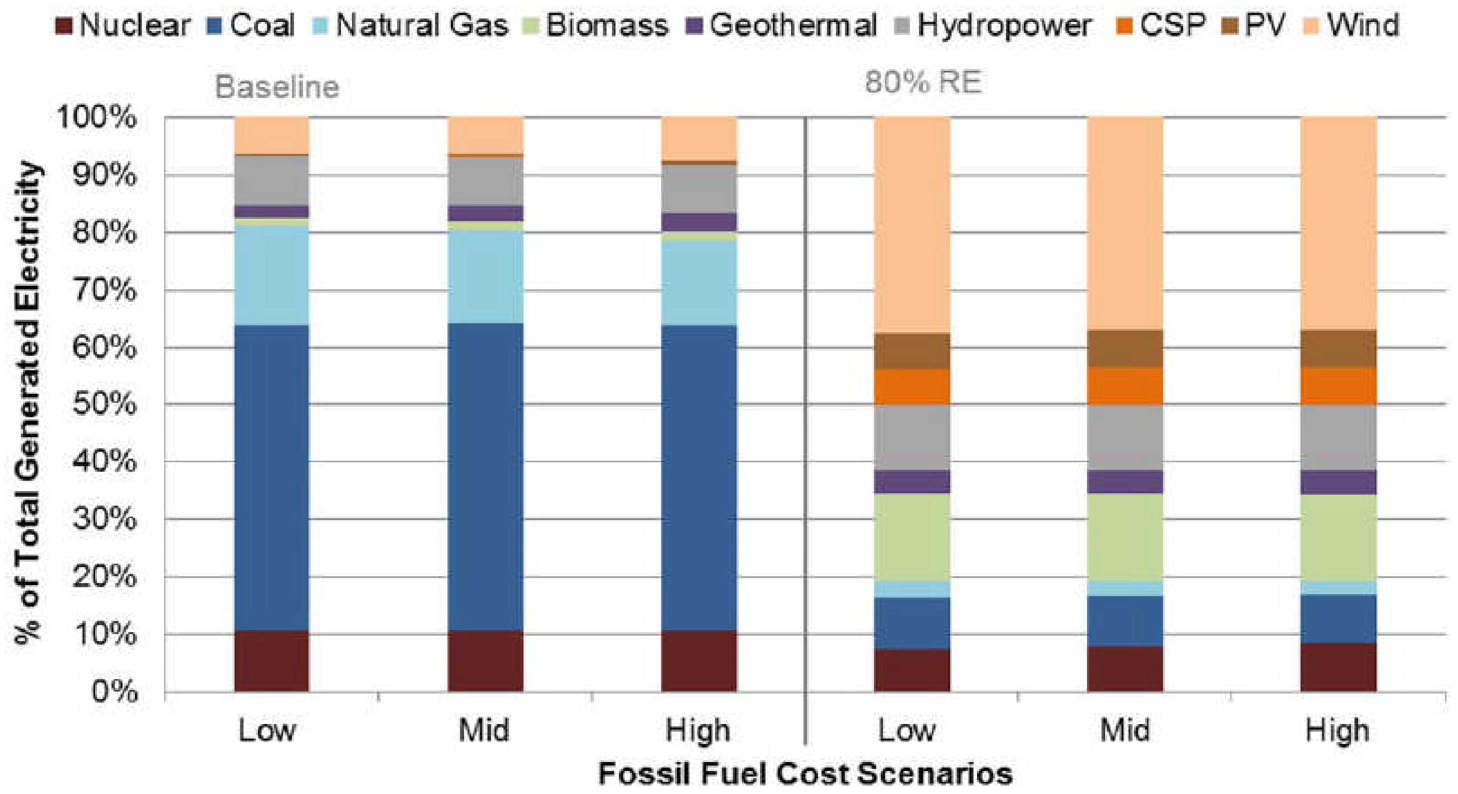


Figure A-12. Generation mix of fossil fuel scenarios in 2050

Can storage dams become pumped storage until global HTS grid becomes commercial

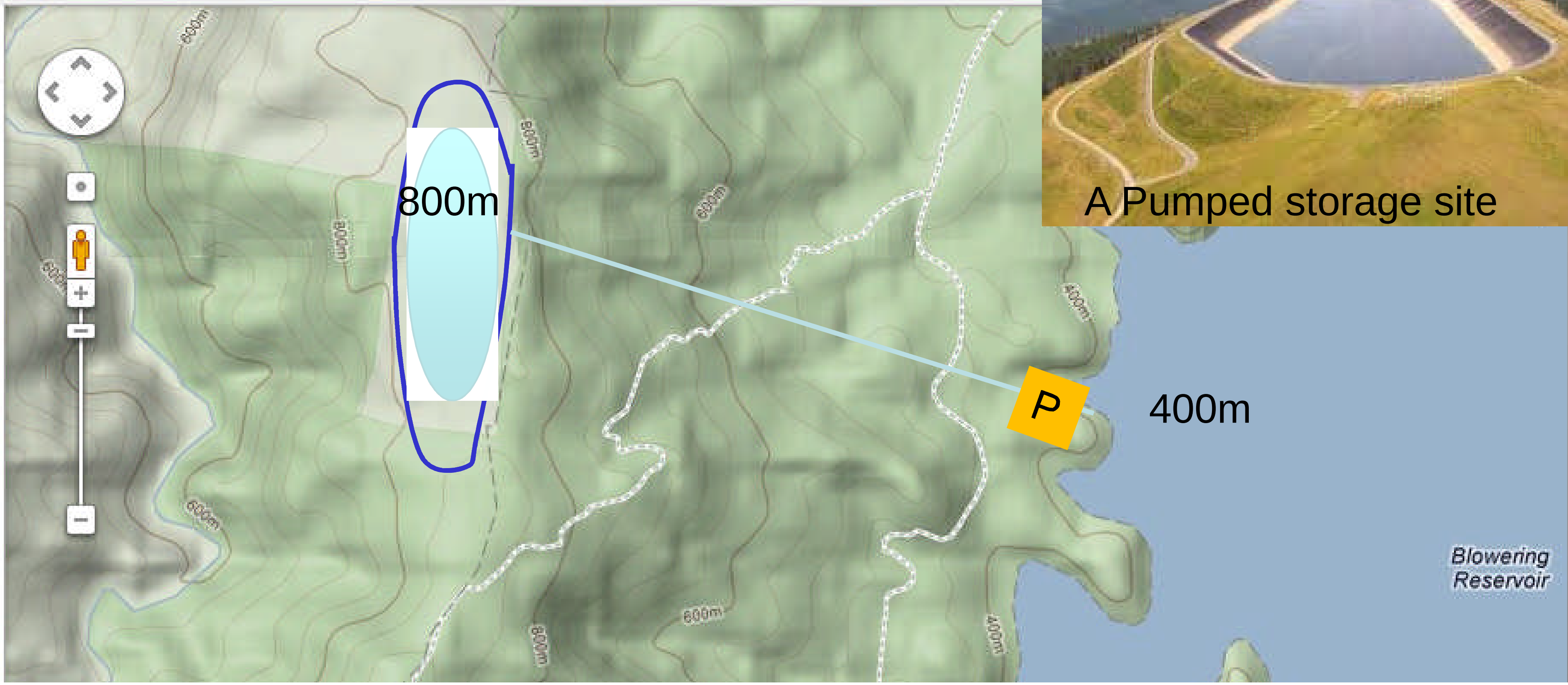
Australia built a lot of dams in the last 100 years but very few have been built in the last 30 years.
Murray-Darling Basin has 24 dams but no new ones since the Dartmouth Dam was completed in 1979.
Most of these dams are for irrigation and flood mitigation when they were built energy was cheap and pumped storage was not useful or viable.

In most of the 2000 to 2010 MDB dams had low levels several below 30% capacity

Pumped storage of 1000MWH needs 9.2GL which is a relatively small amount in dam capacity of 1000GL,if a head of 50M can be found. Storage halves if head doubles.

Placing a small dam of 9.2GL on a valley 50m higher in in the catchment of the 1000GL dam can provide the head. The water can flow between the little and big dam to give the pumped storage. Small dam can even be a ring wall on a hilltop.

A nearby hill top can provide 400m above dam surface




A Pumped storage site

Summary

Wind on a utility scale is expected to grow with tech improvement in turbine sizes based on superconductive genrator windings technology and hv transmission lines.

The retail price of power is already approaching bettering breakeven for residential PV power and solar heating or water and space for the retail customer .

The next step is innovation in, and mass manufacture of next generation heating and cooling appliances that will store the cooling or heating ability for deferred use after the PV or solar heating peak is over for renewable invested retail customers .

Grid demand will drop as retail customers invest in renewable and demand for a storage service will rise as invested customers have an bankable power surplus

Search for cheap storage technologies continues, pumped storage variants are still king, but CAES and Molten salt are in active part of the improvement cycle

The Silver bullet for energy storage is a massive capacity global grid made with HTSuperconducting transmission lines. These will carry what must become the cheap solar PV from the sunny arid parts of Africa, Central Asia, Australia to the rest of the world creating livelihood for subsistence level farmers.

Thankyou