Jones Family Sustainability Plan
2/18/2019

Goal

To produce and store enough solar energy at home to offset the energy we use at home such that we can go off the grid. Once the kids are gone and we both drive electric-only cars and install a heat pump and solar hot water with resistive heat backup, we will need approximately 13.3 MWh/year powered by an 8.1 kW PV array. This is 4.5 times higher power than our current 2003 1.8 kW array, but fortunately only 464 square feet total, which is only 3.2 times larger than our 150 square foot array due to a 58% increase in solar panel efficiency. We also need about 43 square feet for solar hot water. This is about how much space we have on our shade-free southeast facing roof.

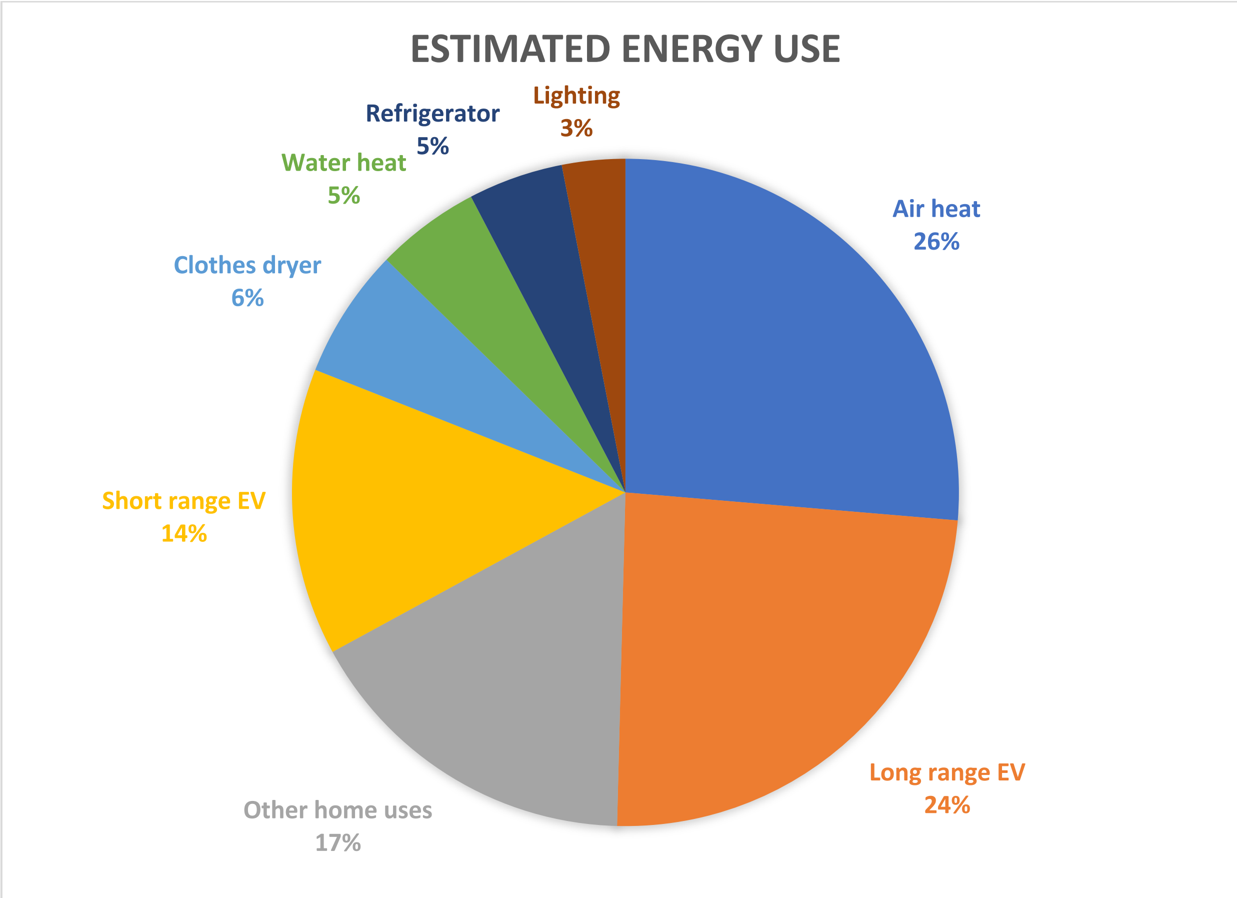
The current goal is to only produce what we use over an annual basis, not including 94 kWh battery storage to allow to be off grid during the winter that would require tripling our array and cost us ~$74K more, or 1.3 MWh battery storage with no additional solar panels that would cost us ~$699K more. Grid or home battery technology may improve in the future but is currently not cost effective for a homeowner.

So to become fully sustainable before battery improvements, we need to dramatically reduce our energy use. Most of our energy need comes from transportation, closely followed by space heating, then clothes dryer, water heating, refrigeration and lighting. Ideas to reduce our energy use include:

- Ride bicycles and walk as much as possible, even more than we are doing
- Upgrade Mustang drive train to AC for improved efficiency
- Switch to small but safe, light but shorter range electric vehicles for around town use, such as the fully enclosed Peraves E-Tracer cabin motorcycle with landing gear except single seat “Teardrop” concept: https://www.youtube.com/watch?v=xzK012GjjX4
- Limit long car trips
- Further lower our thermostat below 68 degrees
- More insulative window coverings
- Wall insulation, if we test and don’t find any other than in the laundry room
- Switch to zone heating, add doors to great room, and not heat great room and kids bedrooms
- Dry clothes on lines inside during the winter and outside during summer even more than what we are already doing

Energy Needs

Item	Need, Wh/year	Min PV Array power, W	Array size, sq. ft.	Notes
Heat	4,300,000	2,356	135	Based on 1.) 441 therms natural gas usage 11/2/17-11/8/2018 = 12.9 MWh, 2.) getting a heat pump with COP of 3.0 down to 32F, plus solar water heater resistive heat assist in winter, about 22% of usage, 3.) 2018 LG 360W monocrystalline, 19% efficient, 2.1 kW out of inverter in 120 sq.ft. or 17.5W/sq.ft. including 1" mounting all around, and 4.) 5 full hours of sun average per day in Santa Rosa, CA; est. 3,440,000 Wh air heat and 660,000 Wh water assuming solar preheat similar 3x improvement as heat pump for air with COP >3
Home lighting and appliances	4,000,000	2,192	126	Original electric bill, based on 2003 usage; clothes dryer est. 822,000 Wh, refrigerator est. 601,000 Wh, lighting est. 400,000 Wh, the rest est. 2,177,000 Wh
Long range EV	3,142,857	1,722	99	Based on eGolf 11,000 miles/year at 3.5 miles/kWh AC
Short range EV	1,818,181	997	57	Based on eStang 4,000 miles/year at 2.2 miles/kWh AC
Subtotal	13,261,038	7,267	417	
Added size of 2003 array			47	12 2003 Sharp 180W monocrystalline, 13% efficient, 1.8 kW, 150 sq.ft.
Solar hot water			43	Assumes 4'x10' flat plate with 1" mounting all around
Total			507	



Create detailed energy use spreadsheet, measuring or estimating power use of all items, then comparing to what if we didn't ride our bikes as much, turned up the thermostat, hadn't added insulation, etc.

Cost Analysis

Expected energy bills for two of us with the 1.8 kW PV moved back in the sun with the eStang and Prius:

$100	electric non-EV
$260	eStang 4 Kmi/yr @ 2 mi/kWh @ $0.13/kWh
$452	eGolf 11 Kmi/yr
$500	gas heat

$1,312 energy bills per year before adding more solar and converting to air source air heat pump

Cost of entire upgrade:

$9,480	for 5.6 kW more PV
$1,649	for solar water heater
$6,000	for air source air heat pump
$5,000	extra paid for next long range EV such as Chevy Bolt above comparable gas car
$22,129	total

16.9 year payback

Warranty and expected life of purchases:

Item	warranty	expected trouble-free life
PV panels	25 year	50 year
PV inverter	10 year	15 year
Solar water heater	5 year	10 year
Air source air heat pump	5 year	10 year
Long range EV	8 year	10 year

We need to look more scrutinously in to the purchases with moving parts – solar water heater, air source air heat pump and long range EV and break out the individual payback. The value of being sustainable is priceless, but if cost scales with non-renewable energy used to create and maintain the products, we might be shooting ourselves in the foot. But adding PVs as we increase our electric load is a no-brainer – no moving parts, so as long as they are built with environmental endurance margin they have no wear parts to worry about. The current PV system has lasted over 15 years trouble free so as long as we get similar quality this should be low risk. LG however may not be as good as Sharp, more research should be done here, considering Sharp isn't available outside Japan or to DIY.

Schedule

Phase	Date	Description	Estimated cost
1	2003	1.8 kW PV installed, covered 75% of house needs	$7,000 after rebate, paid back in 14 years due to lower energy bills
2	Early 2019	Move existing panels to sunny area	Cost of permit, wire and conduit only
3	Late 2020	Add approximately 1.4 kW PV, enough to cover rest of house and eStang, after kids are gone for 1 year and we know our house usage; get one large inverter	$3,705++
4	TBD	Replace natural gas hot water heater once it dies with solar hot water and electric resistive backup	$1,649++
5	By 2025	Replace 2015 Prius with electric vehicle Add approximately 1.8 kW PV panels	$23,000 EV $2,475++ PV
6	By 2034	Replace 2014 natural gas heater with air source heat pump Add approximately 2.4 kW PV panels	$6,000++ heat pump $3,300++ PV
7	TBD	Either be served by grid batteries, or get enough residential batteries to go off grid	TBD

Components

PV Panels

360W LG PV panels from Korea, $495 each: https://www.wholesalesolar.com/1524760/lg/solar-panels/lg-neonr-lg-360q1c-a5-mono-black-frame-solar-panel

- Phase 3: 4 panels, $1,980
- Phase 5: 5 panels, $2,475
- Phase 6: 7 panels, $3,465

Also consider US made Mission Solar: 14% larger so will further limit what we can put on our roof, but US made, tariff-proof, and only 49% of the cost. Owned by 50 year old Korean company OCI.

Also considered US owned and made SunPower, but could not find DIY or non-microinverter models. Don't want to pay for relatively simple installation, and don't want to wait for very busy contractors given low unemployment, a strong building economy and the local fire reconstruction housing boom

Also considered Sharp but they don't seem to be selling to the US anymore. One friend thinks its because they are using them all up domestically.

PV Inverter

7.7 kW SMA Inverter, $1725: https://www.wholesalesolar.com/2931730/sma/inverters/sma-sunny-boy-7.7-us-inverter . Decommission 15 year old 2.5 kW SMA Sunny Boy that was $2,500 before rebate.

Also considered battery backup inverters, but they cost twice about as much, and we don't lose power that often. And if we decommission the 15.4 kWh eStang batteries, that's only 1.1% of our off-grid needs. If large home batteries get much less expensive we can switch out the inverter which will cost only a fraction of what the batteries cost.

Also considered other brands, but SMA is the leader by far and inverters are the weak link for reliability.

Also considered microinverters, but prefer centralized inverter with less parts for expected higher reliability.

PV Roof Mounts

S-5! S-5-S standing seam metal roof mounts, special orderable through Wholesale Solar: https://www.s-5.com/products/clamps-brackets/s-5-s-clamps/

- Phase 3: 10 to 16, depending on layout
- Phase 4: 4 to 12, depending on load capacity of seam

- Phase 5: 12 to 20, depending on layout
- Phase 6: 16 to 28, depending on layout

Determine exact quantities, minus leftovers from phase 1

Circuit Breakers

50 amp 240V breakers, to replace 15 amp breakers currently installed; Home Depot

Solar Water Heater

Solar hot water kit: Duda Solar 15 evacuated tubes plus 26 gallon stainless steel tank with resistive backup heat: https://www.dudadiesel.com/choose_item.php?id=SHS100 , direct from Duda in AL for $1,649 plus shipping

Also consider flat plate collector, cheaper and more durable but larger and heavier.

Air Source Air Heat Pump

5 ton central air source heat pump, recent more efficient cold climate two stage pump and variable frequency drive with >3.0 COP down to 32F, requires contractor: TBD

Considered up to 2x more efficient ground source heat pump, but they only last 50 years until they dry out and transform the ground and its heat conduction, and can be cost prohibitive to trench or drill, costing $10Ks.

Zone Heating Duct System

Zone heating system duct work: insulated steel for efficiency and rodent-proof, may require contractor, TBD

Create detailed component spreadsheet, including panel clamps, conduit, wire, conduit termination boxes, wire staples, hold-down brackets, DC and AC shutoff switches and inverter wall mount material

PV Layout

We need to move the panels to an always sunny south-ish facing area on the roof. The southeast side is the target. It has about 546 square feet but there are several vents and 23% of that is in a triangular space, so we will aim low on overall size based on what fits. Don’t want to continue on garage roof, may get shaded by oak and magnolia in the afternoon.

Do detailed layout sketch, including where to mount panels, boxes and inverters and where to route conduit

Then apply for city and PG&E permits with spreadsheets and sketches

Battery Calculations

Scenario A: Off-Grid With Minimum PV Array Size, $711K

Minimizing the number of solar panels and adding enough battery capacity to get through the lower production winter months. This would only require 8.1 kWh PV array that is approximately $12K, but would be far less cost effective with today's home battery prices; the 1.3 MWh battery would cost $699K for a system total of $711K and take up a large portion of the back yard. See spreadsheet for details.

Off Grid Solar Battery Calculator

need	13,261,038	Wh	
array	7,267.0000	W	
average annual full sun equivalent	5.0	h	
annual surplus	1,245	Wh	target is >0
battery capacity	1,300,000	Wh	
minimum state of charge	21%		target is >20%
number of 13.5 kWh Tesla Powerwalls	96.3		
price at $7,250 per Powerwall	$698,148		

month	need, Wh	monthly production, Wh	surplus, Wh	battery state of charge, Wh	%
Sep	1,105,087	1,105,189	102	1,300,000	100%
Oct	1,105,087	967,040	-138,047	1,161,953	89%
Nov	1,105,087	865,908	-239,178	922,775	71%
Dec	1,105,087	828,892	-276,194	646,581	50%
Jan	1,105,087	865,910	-239,176	407,404	31%
Feb	1,105,087	967,043	-138,043	269,361	21%
Mar	1,105,087	1,105,193	106	269,467	21%
Apr	1,105,087	1,243,341	138,255	407,722	31%
May	1,105,087	1,344,472	239,386	647,107	50%

Jun	1,105,087	1,381,487	276,400	923,508	71%
Jul	1,105,087	1,344,470	239,383	1,162,891	89%
Aug	1,105,087	1,243,338	138,251	1,301,143	100%

Scenario B: Off-Grid With Minimum Battery Size, $86K

We need 13.1 MWh/year or 36.4 kWh/day.

With 5 hours average full sun per day we need a 7.28 kW average peak PV output array.

From experience and supported by modelling, our 1.8 kW array puts out 6 kWh/day in winter, 9 kWh/day in spring and fall, and 12 kWh/day in summer, so we would need 7.28 kW x 9 / 6 = 10.92 kW to produce enough power in the winter on a sunny day, a 50% increase in PV size.

One Tesla Powerwall is $7,250 for 13.5 kWh battery storage, so we need 2.7 of them or $19,548 per day of storage for cloudy or rainy days where PV production can be <10% of average. Storms regularly last 2 to 3 days, so we are talking at least $50K for 94.5 kWh storage in 7 Powerwalls.

But if we assume 50% cloudy days in the winter, we need to additionally double our array size to be able to charge the batteries in parallel with using our cars and appliances during those precious winter sunny days, so that would be a 21.8 kW array, 3 times the minimum solar array size, which is only 1200 square feet vs. 3750 square feet of roof on a 8000 square foot lot, and 62 panels and 3 7.7 kW inverters subtotaling $36K. So this is a total of $86K.

Scenario C: On-Grid With No Battery, $12K

This assumes the grid becomes renewable, which appears to be the most cost effective way to become sustainable due to the economy of scale, but unfortunately although Sonoma Clean Power is committed to procuring and installing renewable energy production, energy storage is in its early stages.

With energy cost savings of approximately $800 $100s per month this method will take decades to pay off which is but This seems to be the most cost effective way

Scenario D: On-Grid With No Battery or PV, $0

Once the grid becomes renewable with storage then consumers will not have to do anything. This will probably happen abruptly however since once cost effective energy storage is solved, the energy production will be even more mature and cost effective.

Clothes Dryer Analysis

Our resistive heat clothes dryer died after ~18 years in Feb 2019, melting at a failed wire harness and emitting smoke, causing a fire risk to the house. We looked at heat pump dryers, a favorite being the Bosch due to least bad reviews and overall high quality rating:

Heat Pump Clothes Dryers 240V, white 2/13/2019

make	model	width, in	cu. ft.	price	rating	availability	link
Home Depot:							
Bosch	WTG86400UC	24	4	$989	3.6/5	deliver by Feb 18	link
Electrolux	EFDE210TIW	24	4	$898	3.9/5	deliver by Feb 18	link
LG	DLEC888W	24	4.2	$798	4/5	deliver by Feb 18	link
Samsung	DV22N6800HW	24	4	$1,079	4.7/5	deliver by Feb 19	link
Whirlpool	WHD5090GW	24	4.3	$947	3.4/5	deliver by Feb 18	link
Whirlpool	WED7990FW	27	7.4	$1,259	3.8	out of stock	link

Lowes carries all of these brands too
TeeVax starts at $1,149, only 24"
Asiens: start at $1,299, only 24"
Pacific Sales: none with heat pump, condenser or ventless in title
Best Buy has none available within 250 miles of Santa Rosa even for shipment…why?
Brands not included:

- Miele: too expensive and low rated overall for quality, probably due to complexity
- GE: low rated by purchasers and overall for quality
- Summit Appliance: new/no name and hence not enough quality data

But there are a lot of disadvantages to a heat pump dryer:

Issue	Resistive Heat	Heat Pump
Laundry cycle time per 27” washer load	2 hours: 1 hour wash, 1 hour dry	5 hours: 1 hour wash, 2 hours dry but 2 dryer loads needed per wash. 2.5x worse. Tried hanging clothes to dry inside the house on clothes lines, but in this coastal winter weather and minimal air heater use it takes up to 3 days to dry jeans, a risk of molding.
Purchase price	$500-$700	$800-$1,100
Capacity	27”, 7.0 cu. Ft.	24”, 4.0 cu. ft: only readily available size, 56% of 27”, probably due to ventless apartment/European and Asian dense housing market fit. Able to do thin blankets but not thick synthetic comforters or sleeping bags, but that’s OK we’ve been bringing them to laundromats anyway to save our consumer grade front load washer bearings which went out after <<10 years on our first one
Moving parts	Drum only	Drum, heat pump and drain pump; probably will need to spend more on maintenance, and it could become cost ineffective like front load washer and refrigerator which were going to cost almost as much to repair than replace
Energy use	$107/year for 822 kWh at $0.13/kWh, assuming 3 loads per week running 1 hour each at 240V/11 ohms = 21.8 amps	$75/year assuming 575 kWh or 30% less energy use; $32 savings per year, 9.4 year payback, longer than warranty but shorter than expected 10 year trouble-free life, assuming similar to our Maytag top freezer refrigerator.
Hole in wall for vent	yes	No

But adding only 0.247 MWh more PV to accommodate resistive heat is only 1.9% of our total 13.261 MWh need, so it’s not worth the inconvenience of 2.5x laundry cycle time, especially since the payback time is not compelling and actually risky. So proposal is to maximize use of indoor and outdoor clothes lines in winter and summer and minimize resistive heat dryer use, with moisture sensor so it stops drying when things are dry, as we had in our previous dryer.