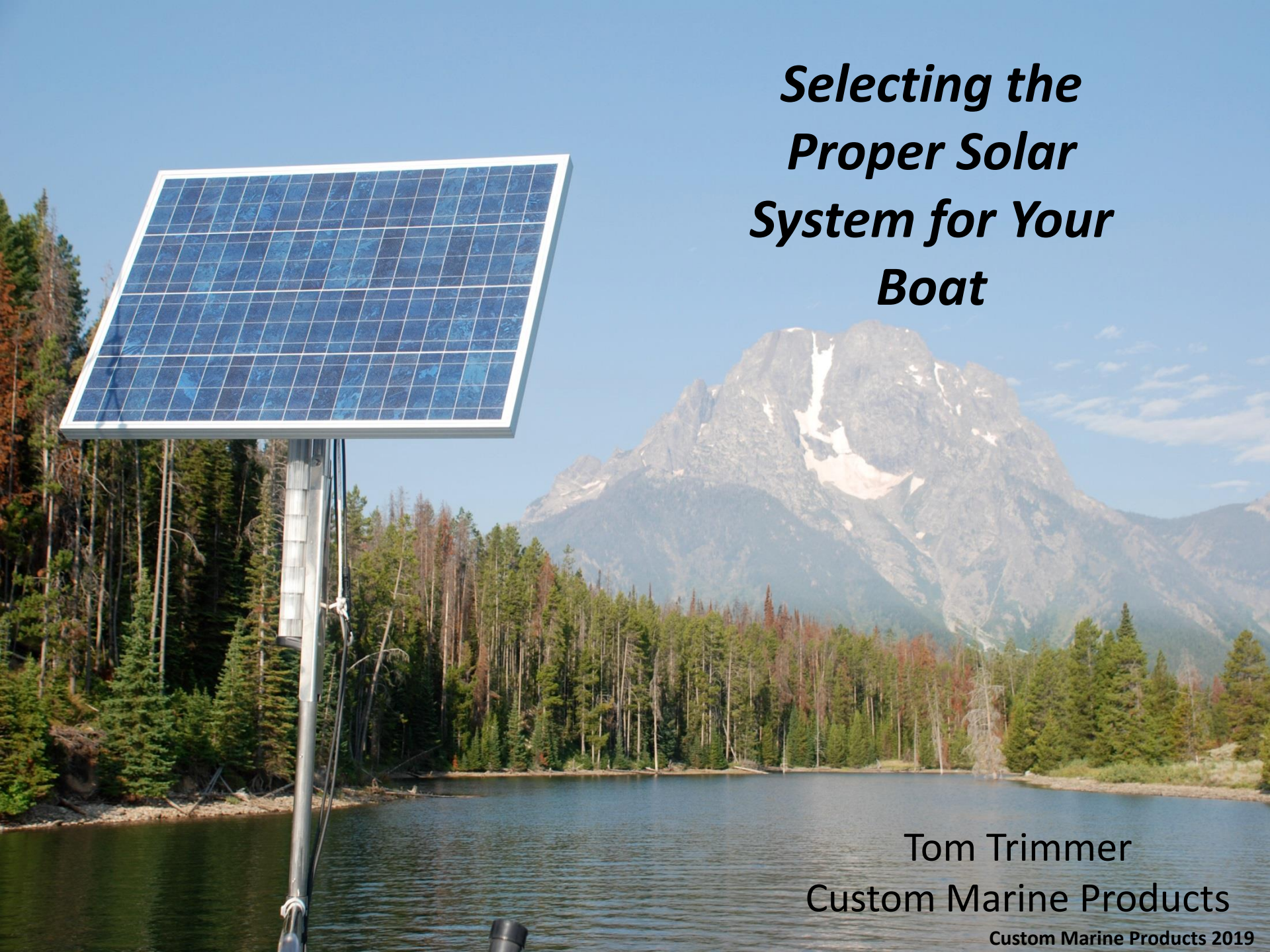
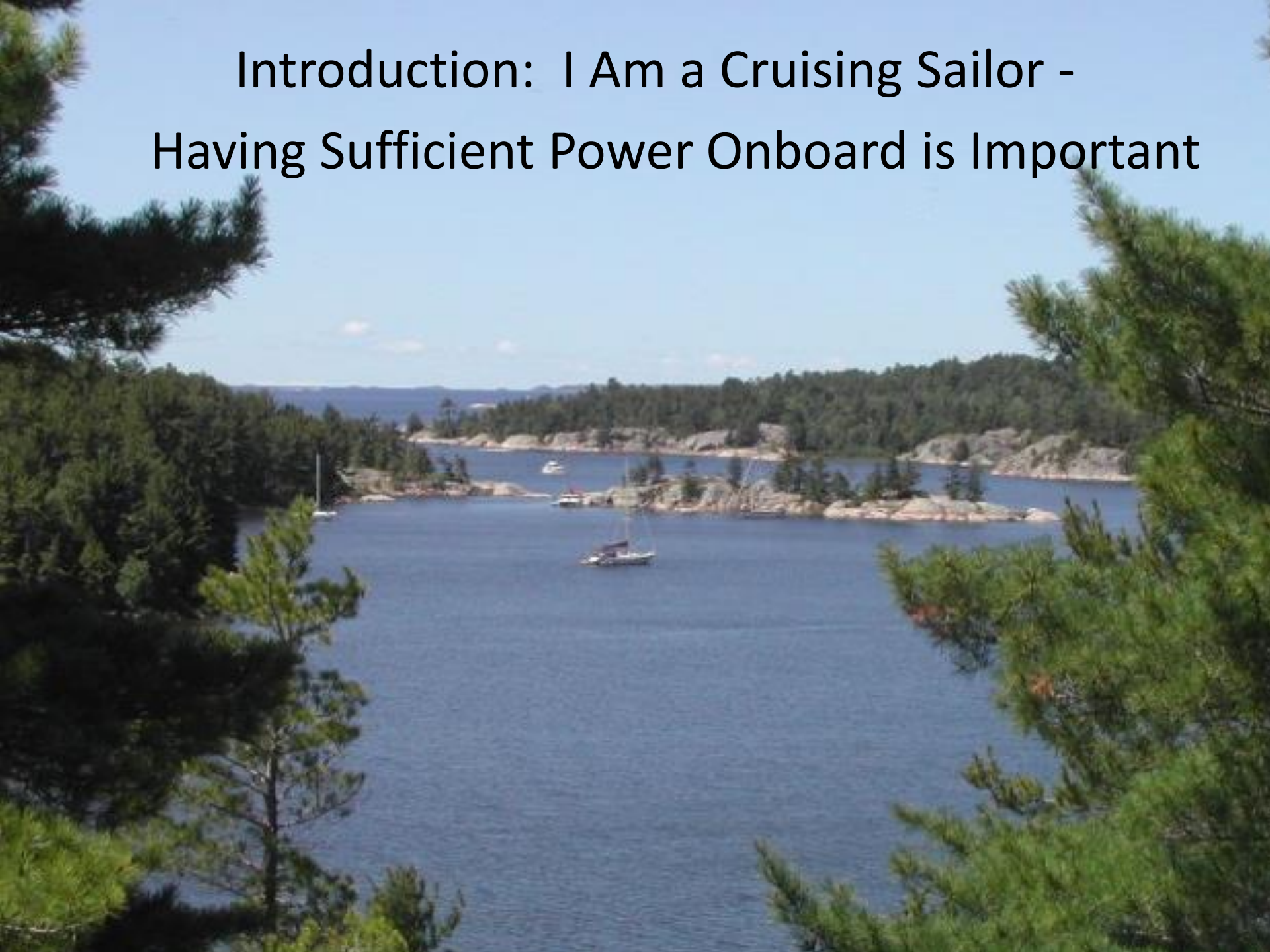


Selecting the Proper Solar System for Your Boat

Tom Trimmer
Custom Marine Products

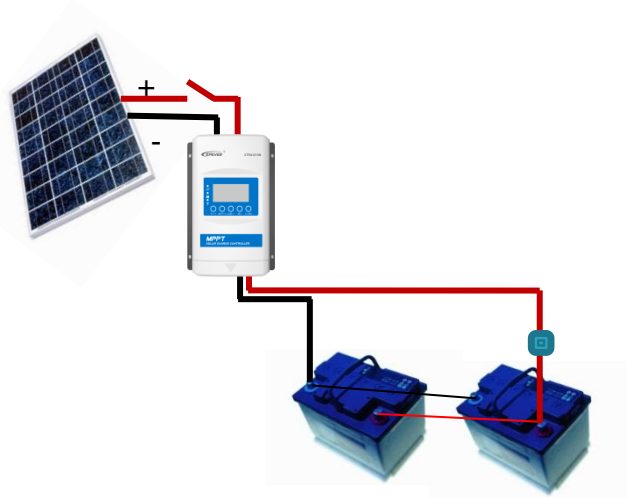
Introduction: I Am a Cruising Sailor - Having Sufficient Power Onboard is Important



Refrigeration started my quest for POWER

Topics for Discussion

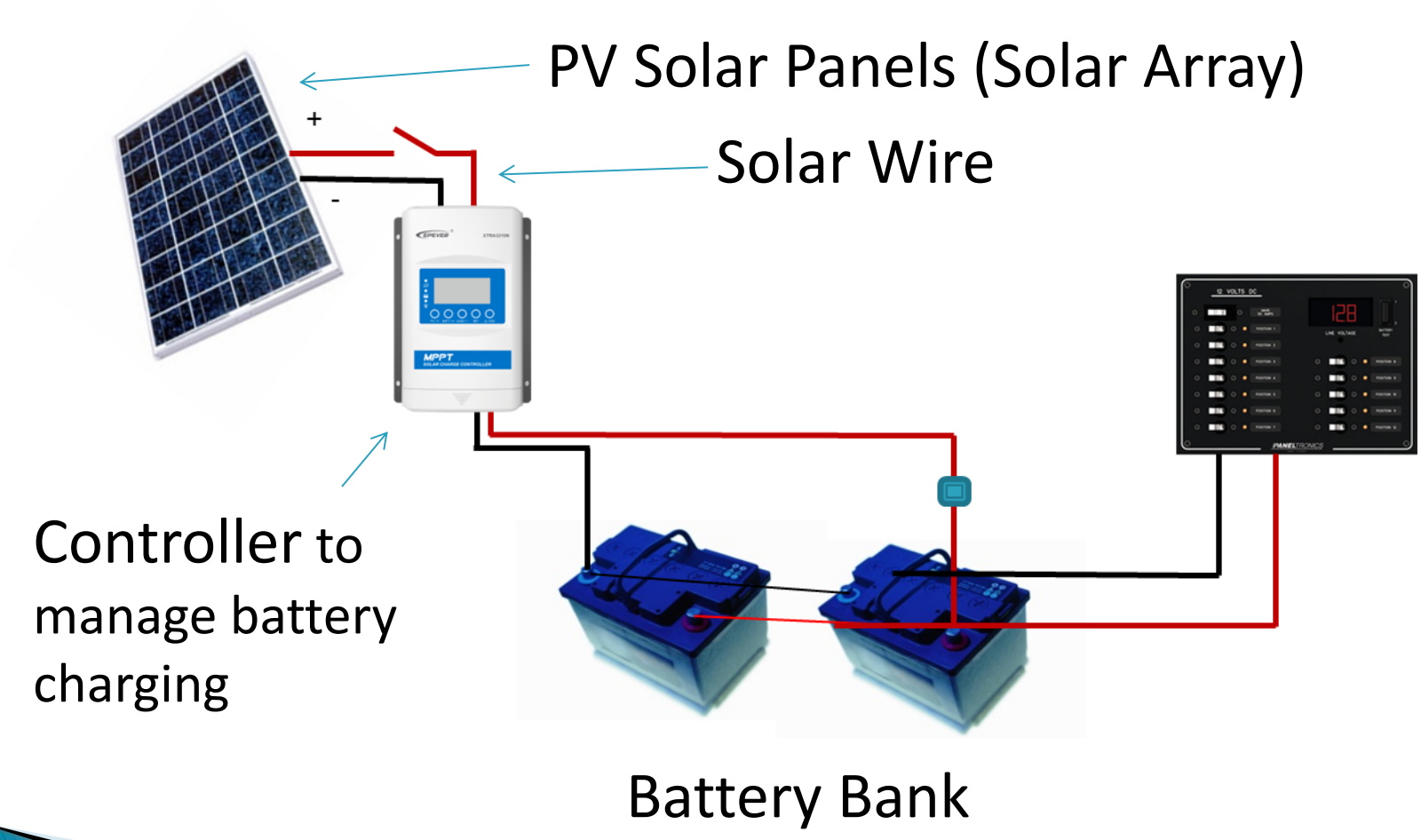
- Introduction to PV solar panels
- Introduction to solar controllers
- What is a balanced solar system?
- Designing your solar system
  - A case study
- Selecting the proper equipment
- Installation ideas
- Q & A



Slides at: custommarineproducts.com
Support, Manuals & Info

Components of a PV Solar System

(**P**hoto**V**oltaic)



A Few things to Know About PV Solar Panels

(PhotoVoltaic)

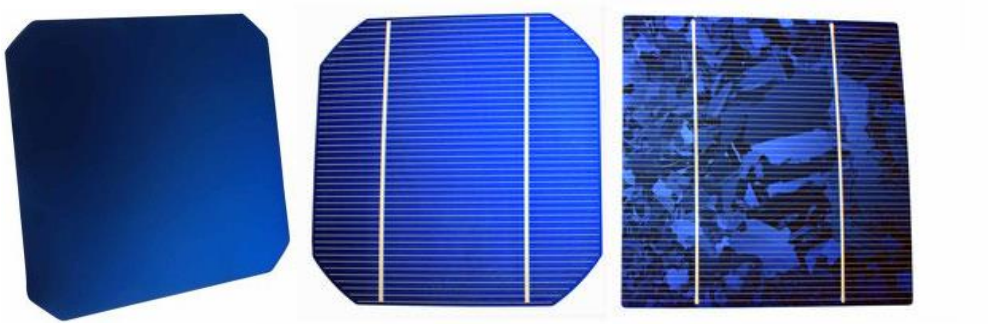
Monocrystalline or Polycrystalline?

Grade A or B or C?

Rigid or Semi-flexible?

Commercial or Marine?

Monocrystalline or Polycrystalline?



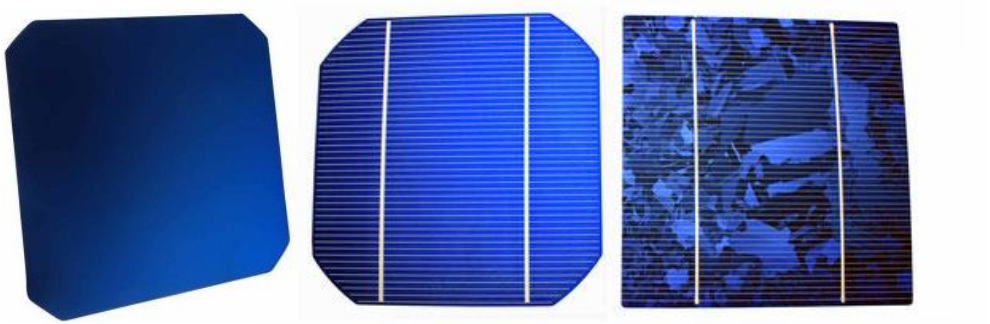
Monocrystalline

- Generally higher efficiency solar cells 16 % to 24%
- Generally higher output than polycrystalline in full sun
- More expensive than polycrystalline ($3 - $8 per watt)

Polycrystalline

- Cell efficiency typically 13% to 16%
- Generally less sensitive to shading and clouds than monocrystalline
- Less expensive that monocrystalline ($2 - $5 per watt)

Monocrystalline or Polycrystalline?



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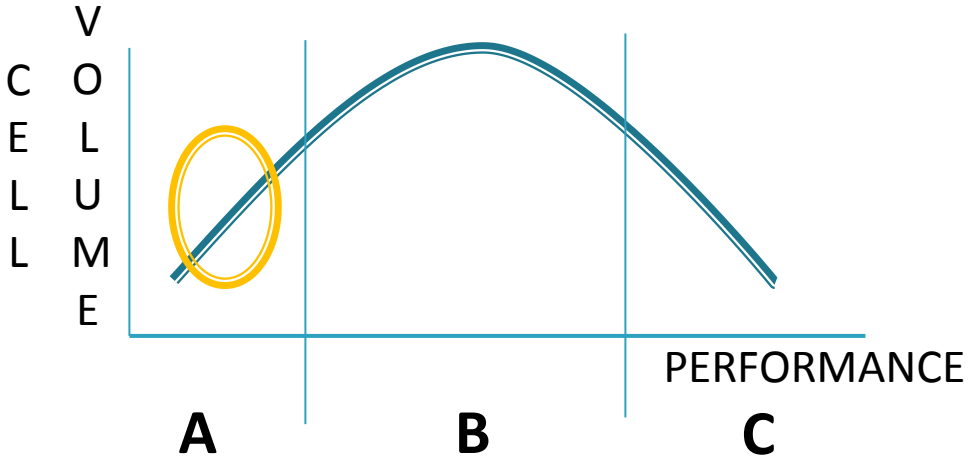
Note: Efficiency of thin-film panels is only 7% - 12%

Grade A or B or C?

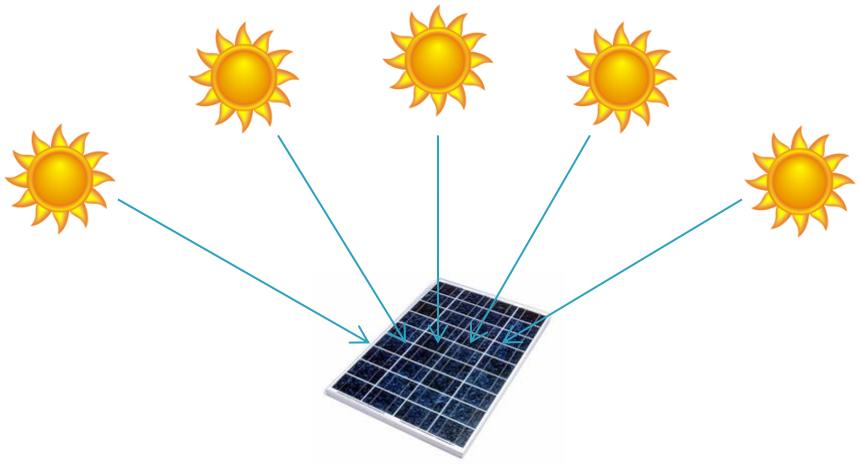


All solar cells are not created equal

- Cells are graded under a standard artificial light and sorted by power output.
- The distribution of performance is a Bell Curve with most cells being a B grade.
- **Grade A will typically perform above rating in full sun light.**
- Grade B is typically used for residential and solar farms.
- **Grade A+ is desirable on a boat where space is limited.**

We want maximum output per square inch.

Why the Quality of Solar Cells is Important



Average sun hours in a typical day
– 5 hours –

It's all about **watt hours**

Higher performance solar cells produce more power at sub-optimal sun angles than lower performance solar cells - up to 30% more power.

A lower performance 100 watt panel will produce up to 100 watts x 5 hours or 500 watt hours in a day.

A higher performance 100 watt panel will produce up to 650 watt hours in a day.

That's 150 watt hours or 12.5 amp hrs. more power

Rigid or Semi-flexible?

SunPower semi-flexible panel performance is comparable to rigid panels

Rigid panels

- Have a life of at least 15 years - robust
- Excellent for pole, frame and davit mounting

Semi-flexible panels

- Have a life span of at least 7 years
- Excellent for bimini and cabin top mounting
- Light weight
- Can be walked on
- Sensitive to shading

Rigid or Semi-flexible?

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- Have a life of at least 15 years - robust
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Semi-flexible panels

- Have a life span of at least 7 years
- Excellent for bimini and cabin top mounting
- Light weight
- Some can be walked on (not recommended)
- Some are sensitive to shading

How is a Marine Solar Panel Different from a Commercial Solar Panel?

Marine Solar Panel

- Junction box is filled with inert silicone to prevent corrosion
- Rigid panels have strong frames and extra sealants
- Panels have high output power performance – Grade A+ cells
- Output compatible with 12 or 24 volt battery bank systems
- Panel is wired to accommodate shading

Commercial Solar Panel

- Junction box not filled with inert material
- Frames designed for rack mounting
- Output typically 30+ volts
- Panel cells are typically Grade B or B+

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Commercial Solar Panel

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- Frames designed for rack mounting
- Output typically 30+ volts
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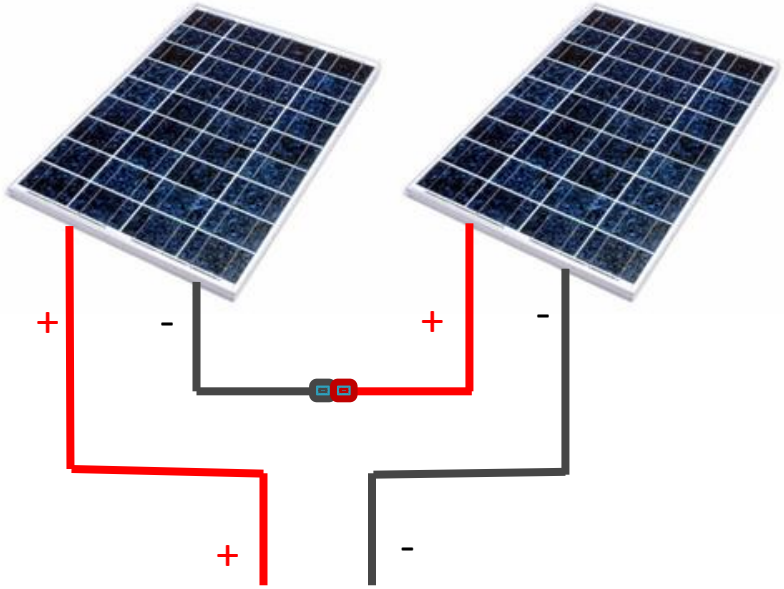
Wiring Multiple Solar Panels

100 Watt, 18 Volt, 5.6 Amp

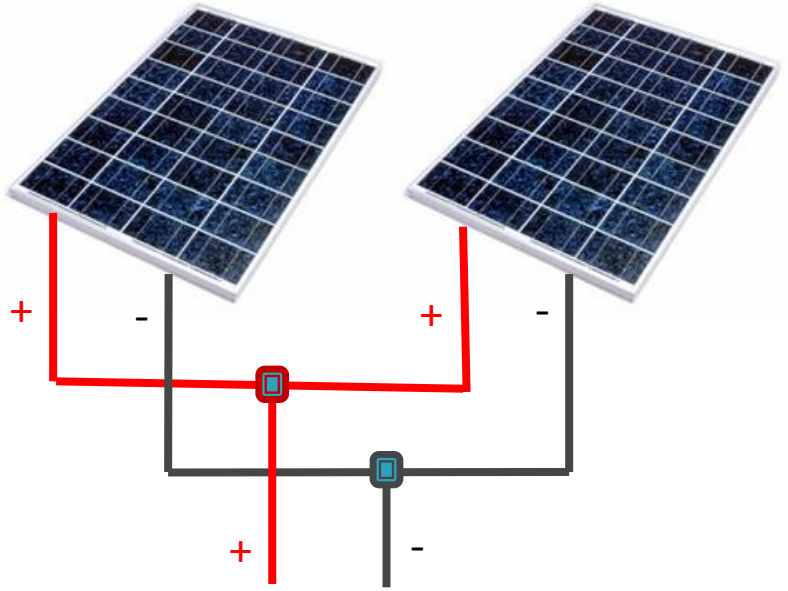
Series



36 Volts

5.6 Amps

Parallel



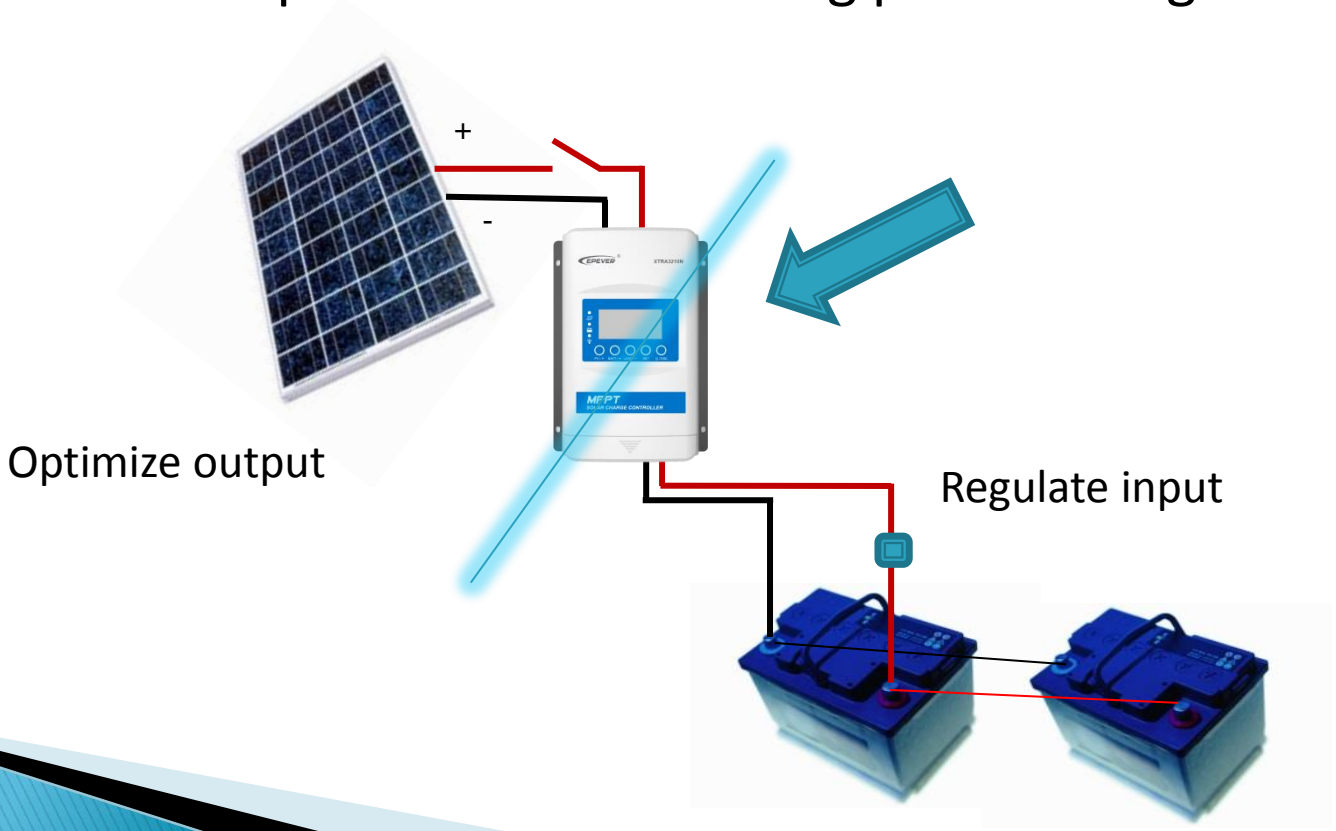
18 Volts

11.1 Amps

A Few Things to Know About Solar Controllers

The purpose of a solar controller is to:

- Optimize the power output of the solar array
- Regulate the amount of power going to the battery bank
- Prevent battery bank overcharging and overheating
- Prevent solar panels from absorbing power at night



There Are Two Types of Solar Controllers

(PWM) Pulse Width Modulation

- Pulse width modulation provides efficient battery charging
- Streams full power to battery bank when bank is low
- Useful if panel voltage is similar to battery voltage
- Less expensive than MPPT controllers

(MPPT) Maximum Power Point Tracking

- Essential to use with commercial solar panels (usually above 30 volts)
- Optimizes power from the solar array
- Reduces voltage to 14 volts and increases amperage

  Pw = V * I (Watts = Volts x Amps)
- Of little value for panels rated under 20 volts and for small solar arrays (under 200 watts).
- More expensive than PWM controllers

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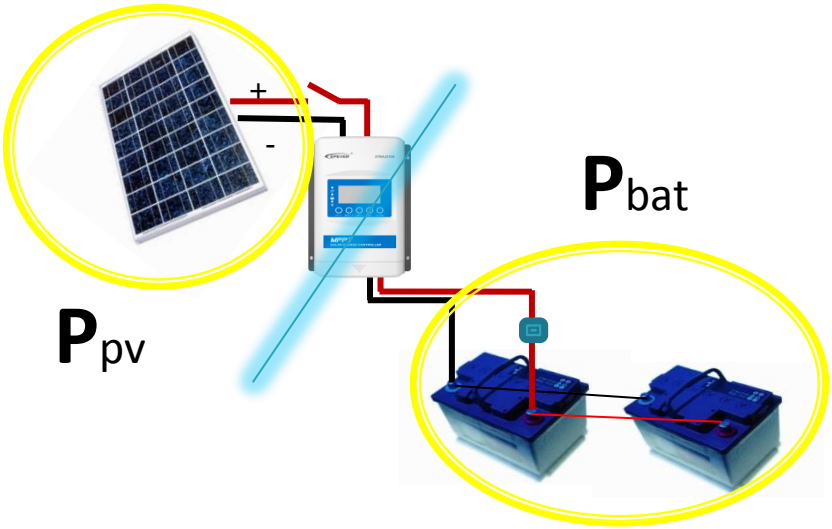
Maximum Power Point Tracking Technology



Input power (**P**pv) = Output power (**P**bat)

200 W = 200 W

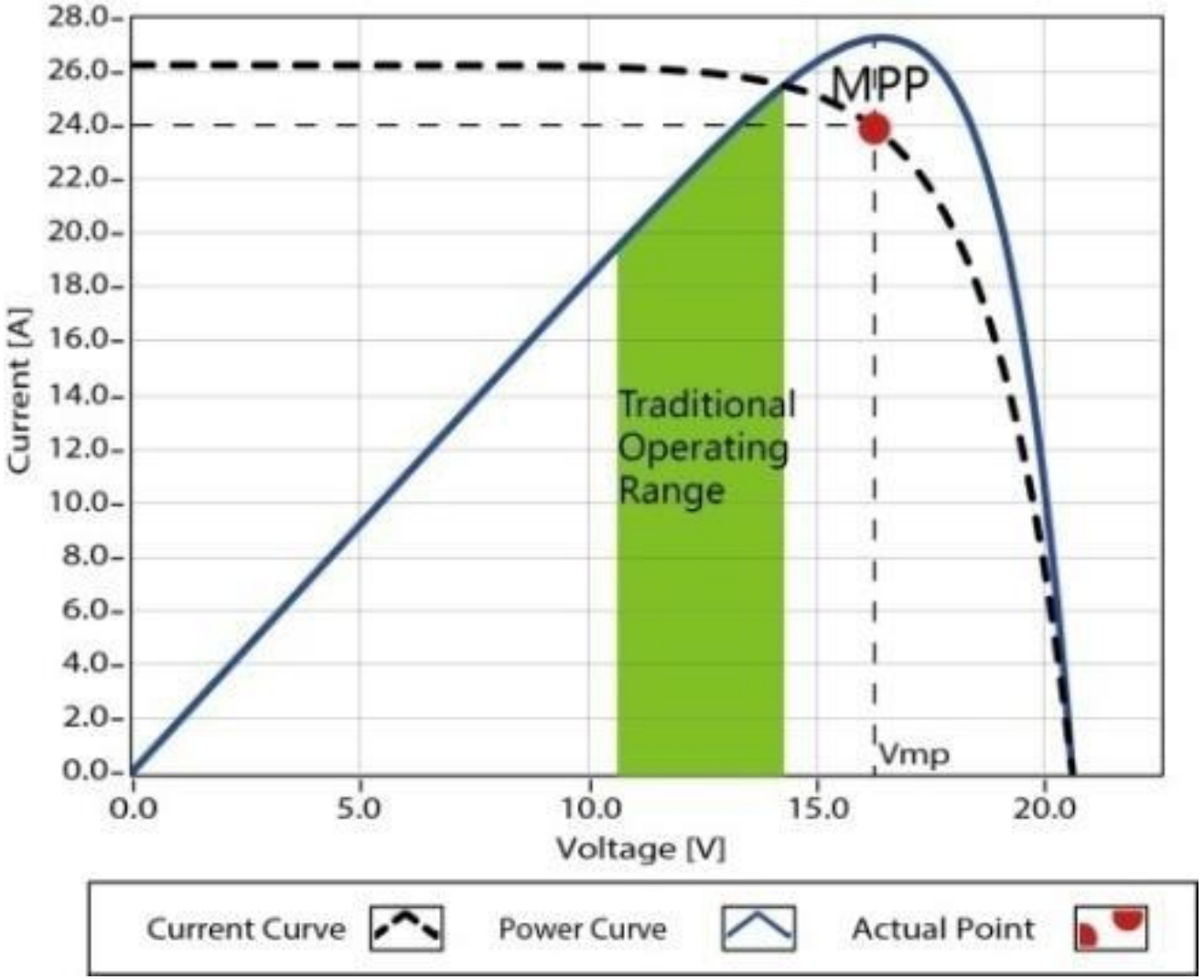
P = V x I Watts = Volts x Amps

Input Voltage (**V**mpp) **x** Input Current (**I**pv) = Battery Voltage (**V**bat) **x** Battery Current (**I**bat)

16-22 Volt Panel	18	x	11.1	=	14 x	14.3
25-45 Volt Panel	36	x	5.6	=	14 x	14.3

At 100% conversion efficiency

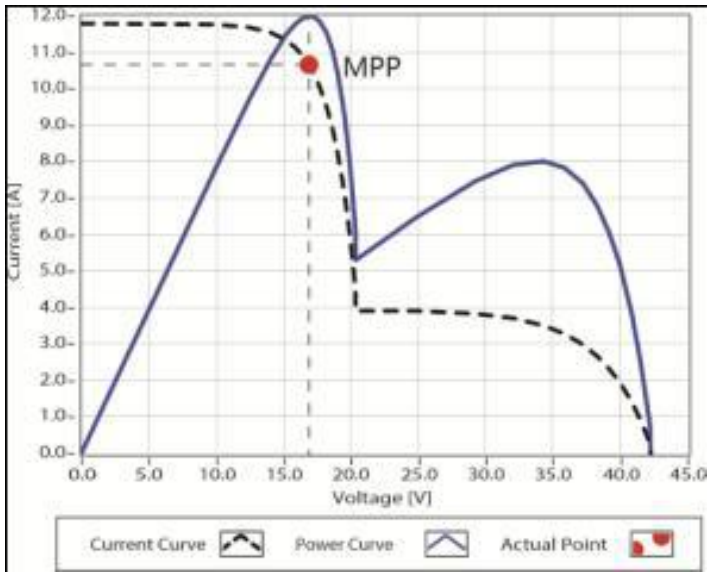
Maximum Power Point Curve

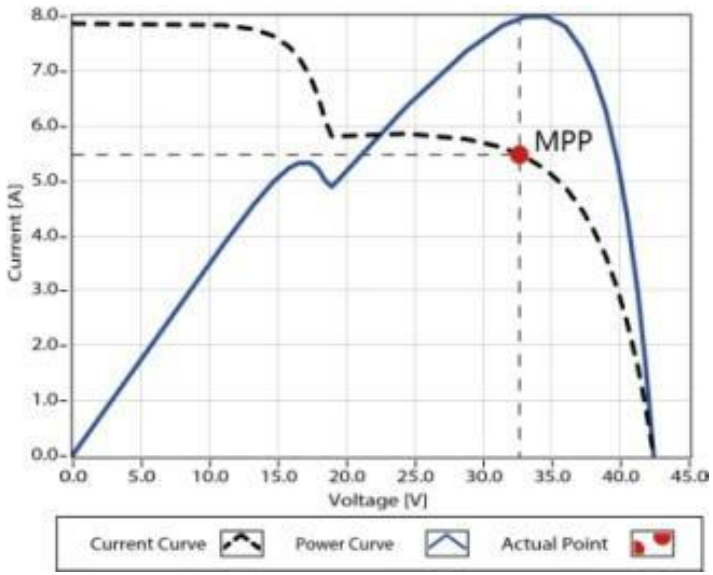


EP Solar

Maximum Power Point Tracking Technology

Impact of Shading and Dissimilar Panels

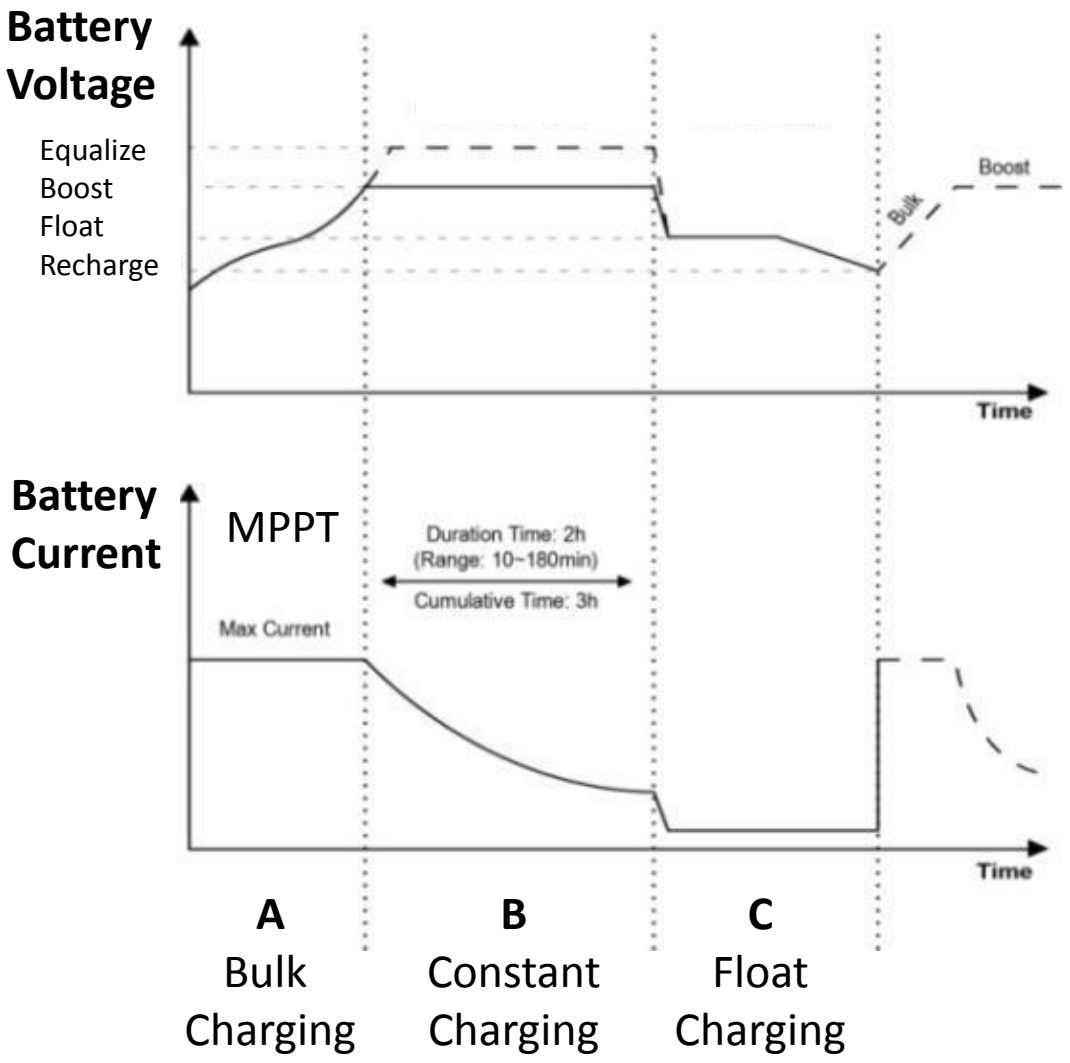




EP Solar

Multi - MPP

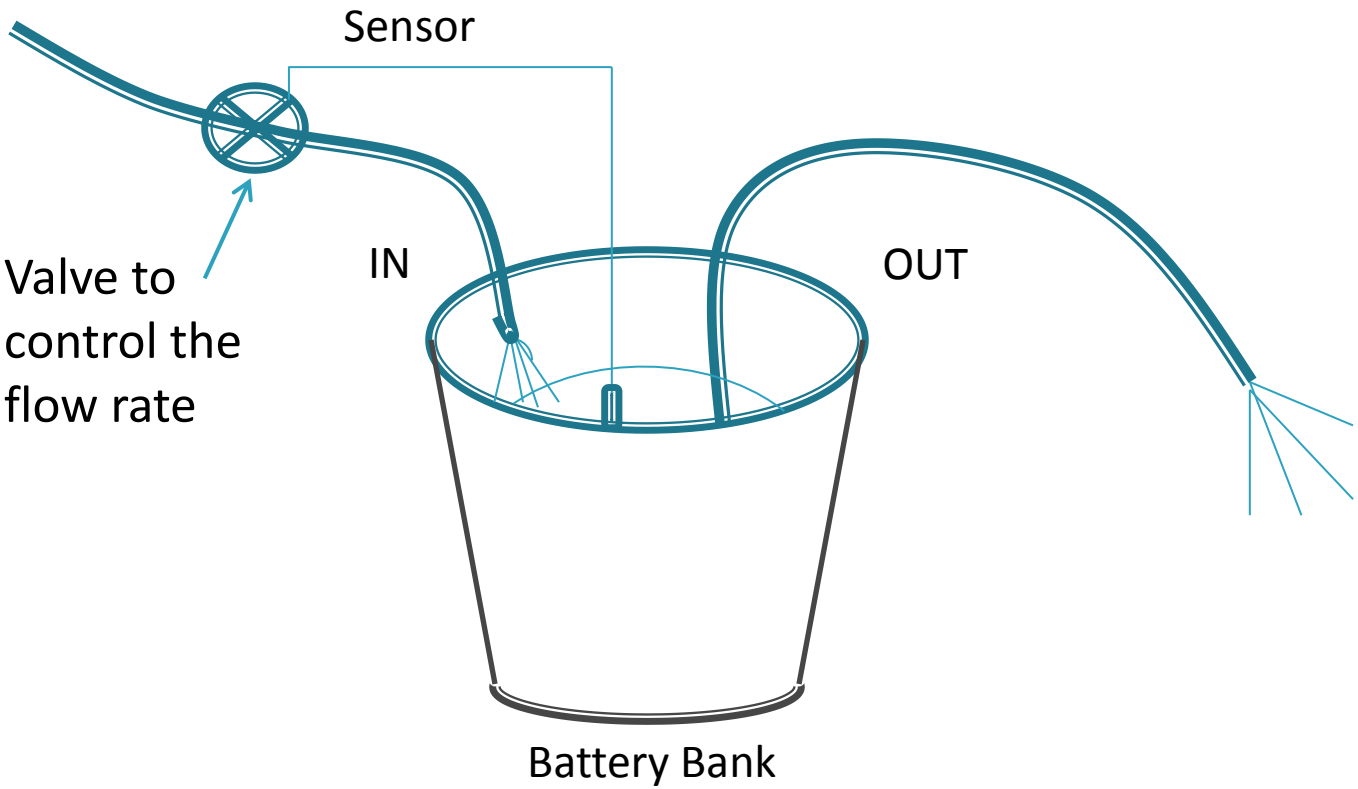
Battery Charging Stage Curve



EP Solar

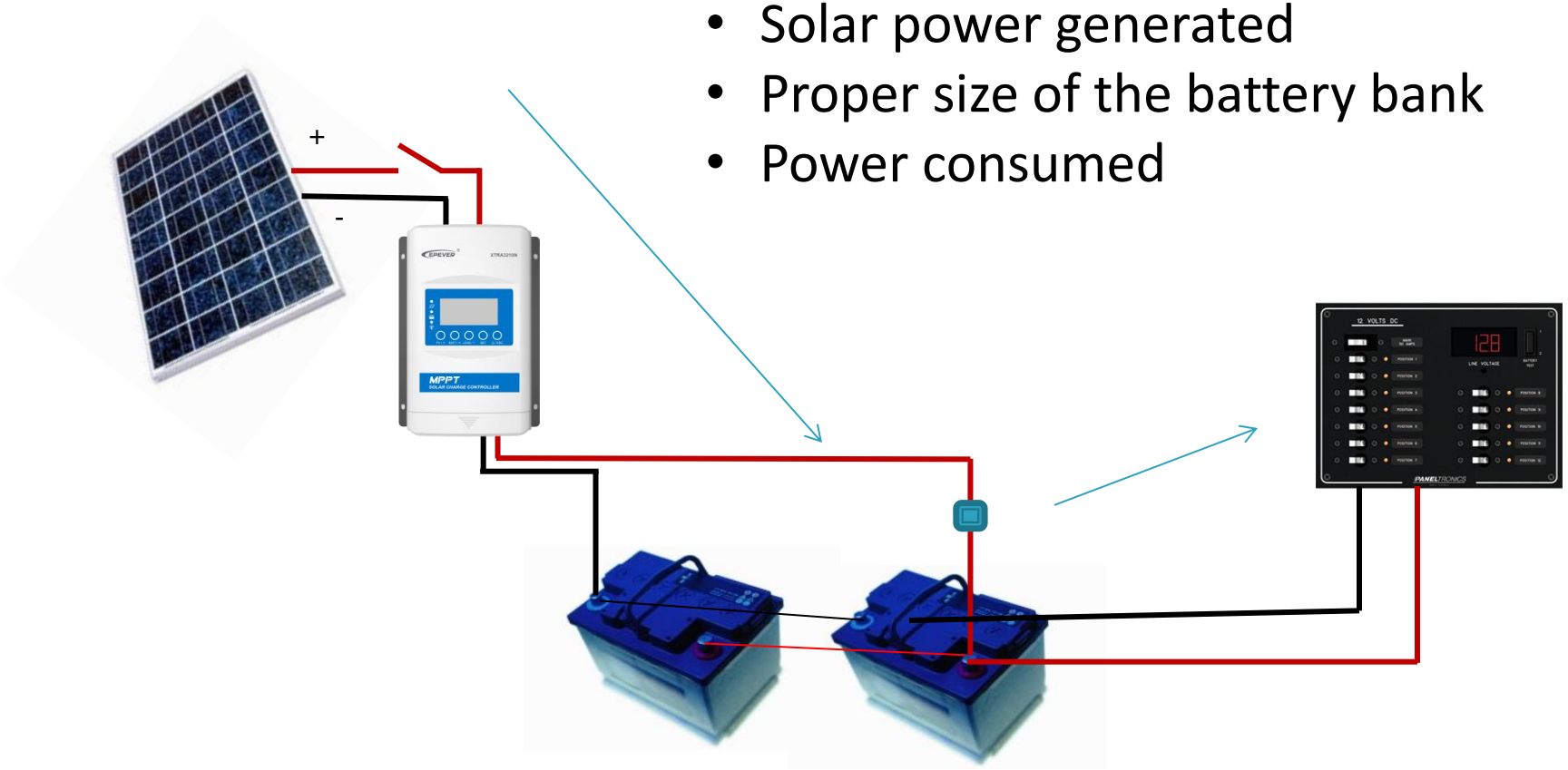
A Balanced System

- Water in
- Size of the bucket
- Water consumed



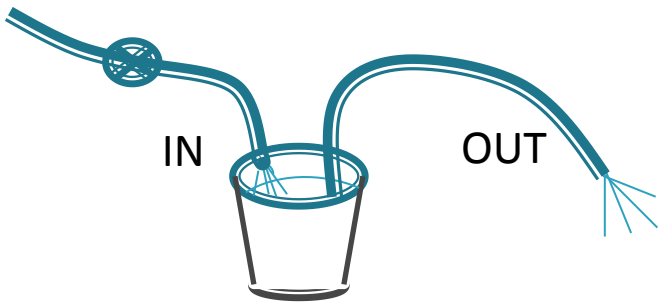
A Balanced System

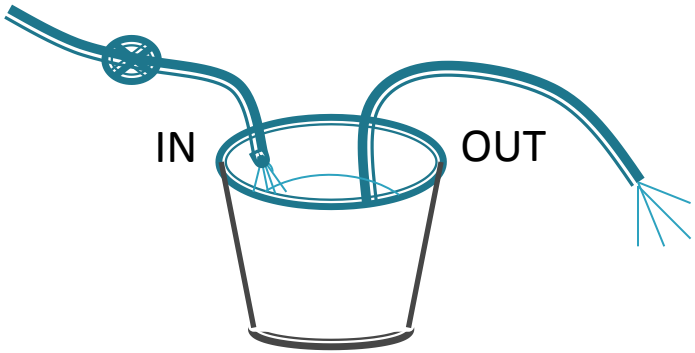
- Solar power generated
- Proper size of the battery bank
- Power consumed



Sizing Your Battery Bank

Battery capacity is measured in Amp Hours





A limited capacity battery bank

- Unable to store all the power your solar panel produces
- No reserve for cloudy days
- Must always be monitored because continually stressed

Your battery bank should have the capacity to support your boat's power requirements for at least 24 to 48 hours

Designing a Solar System to Meet Your Needs

Our Case Study Boat

What Do You Want to Achieve with Your Solar System?

A. Keep the batteries charged while on a mooring.

B. Supplement current power generation capability.
(Run my engine less to charge the batteries)

C. Generate all the power needed while at anchor.

D. Generate all the power needed on passage and at anchor.

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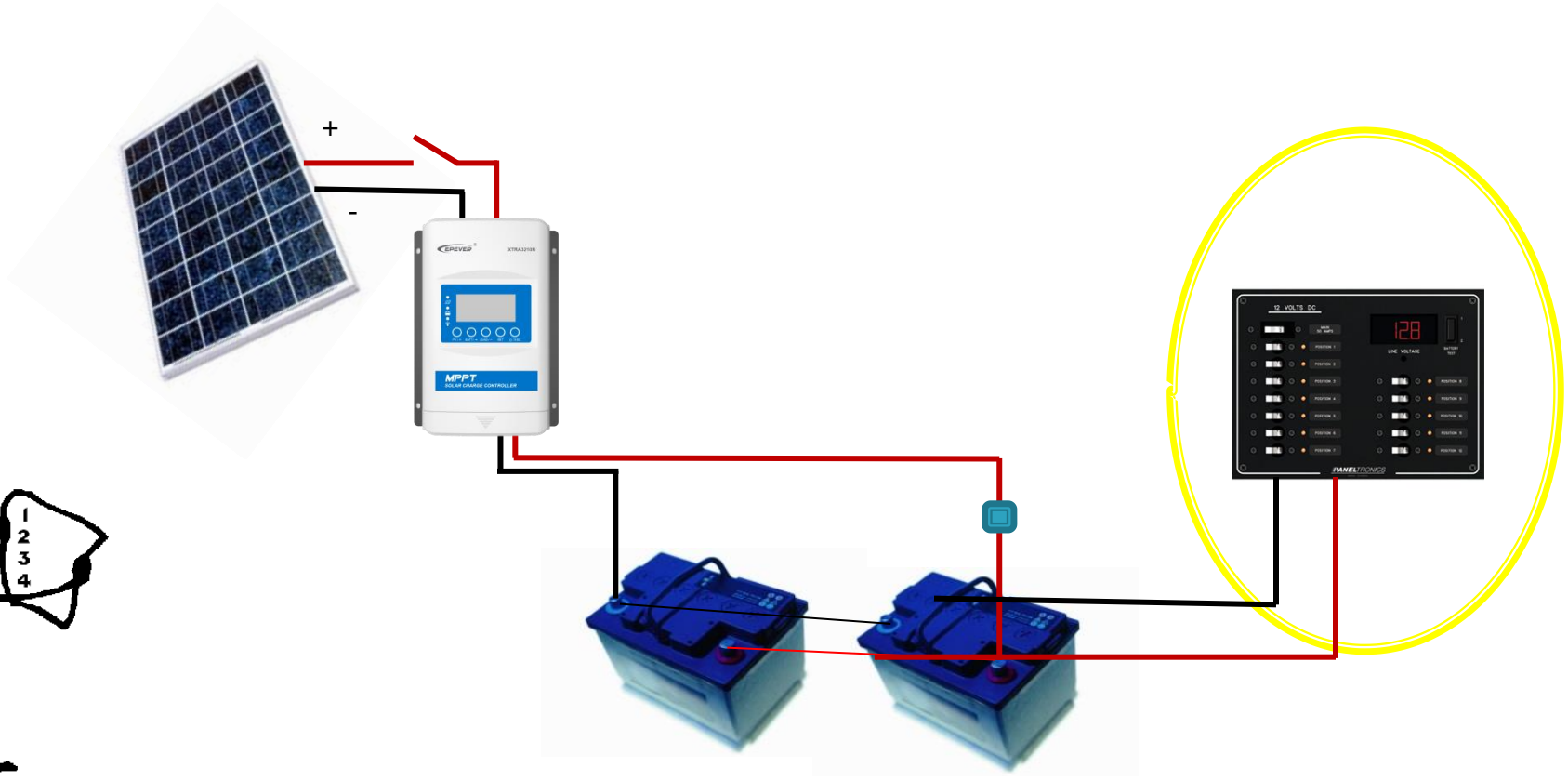
Designing a Solar System to Meet Your Needs

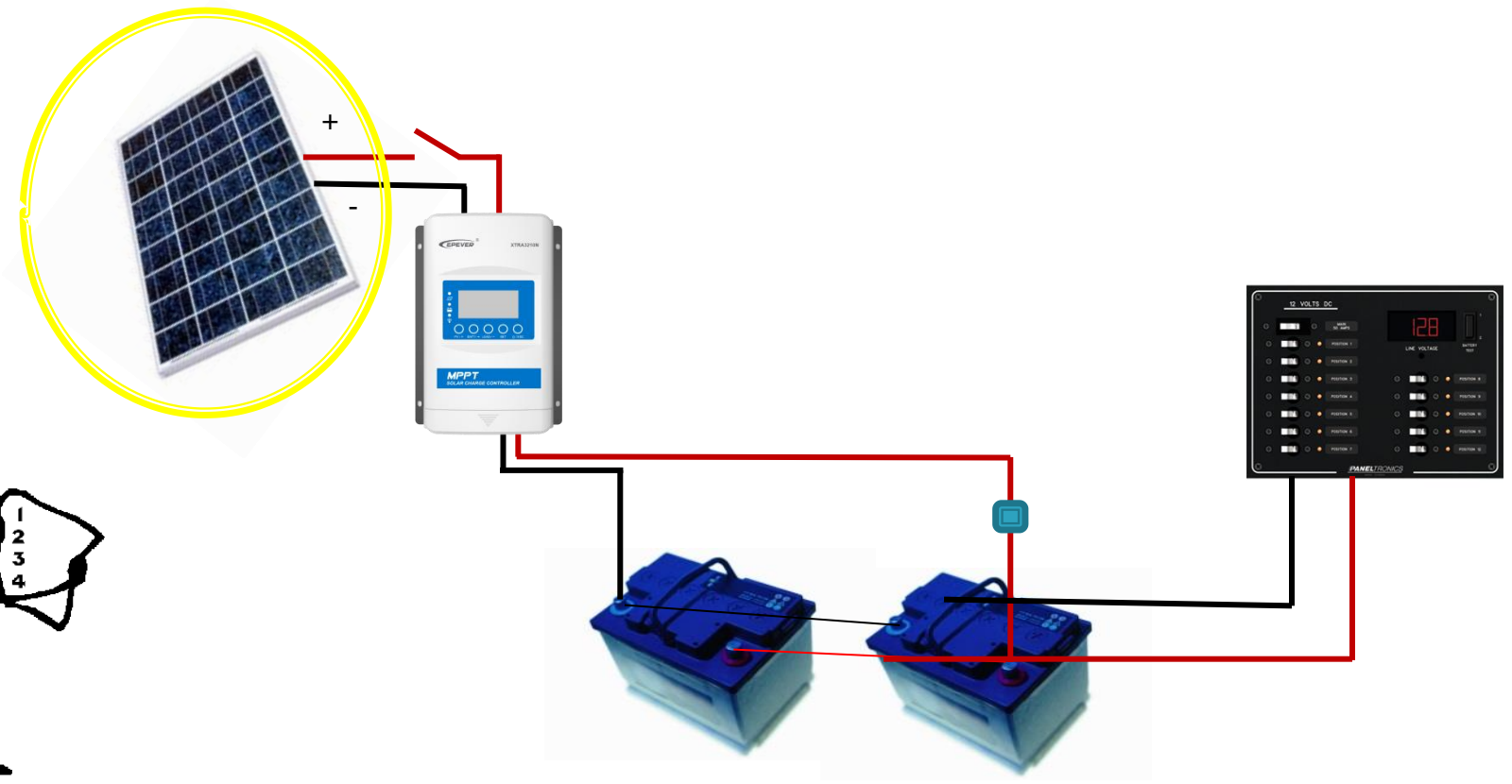
1. Determine daily power consumption

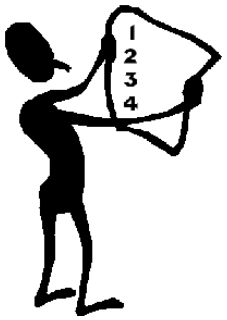


1

Designing a Solar System to Meet Your Needs

1. Determine daily power consumption
2. Determine solar generation capacity needed





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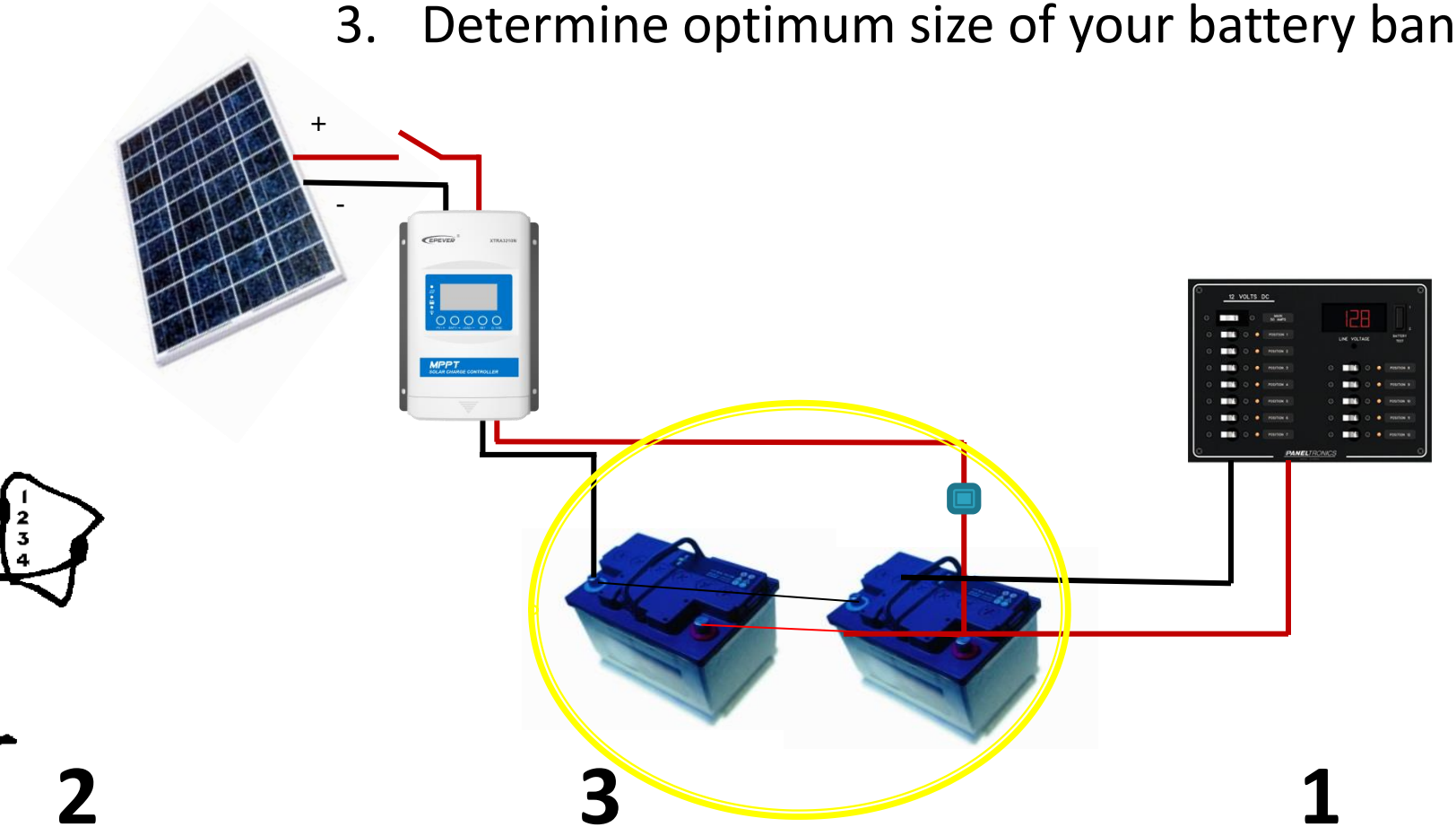
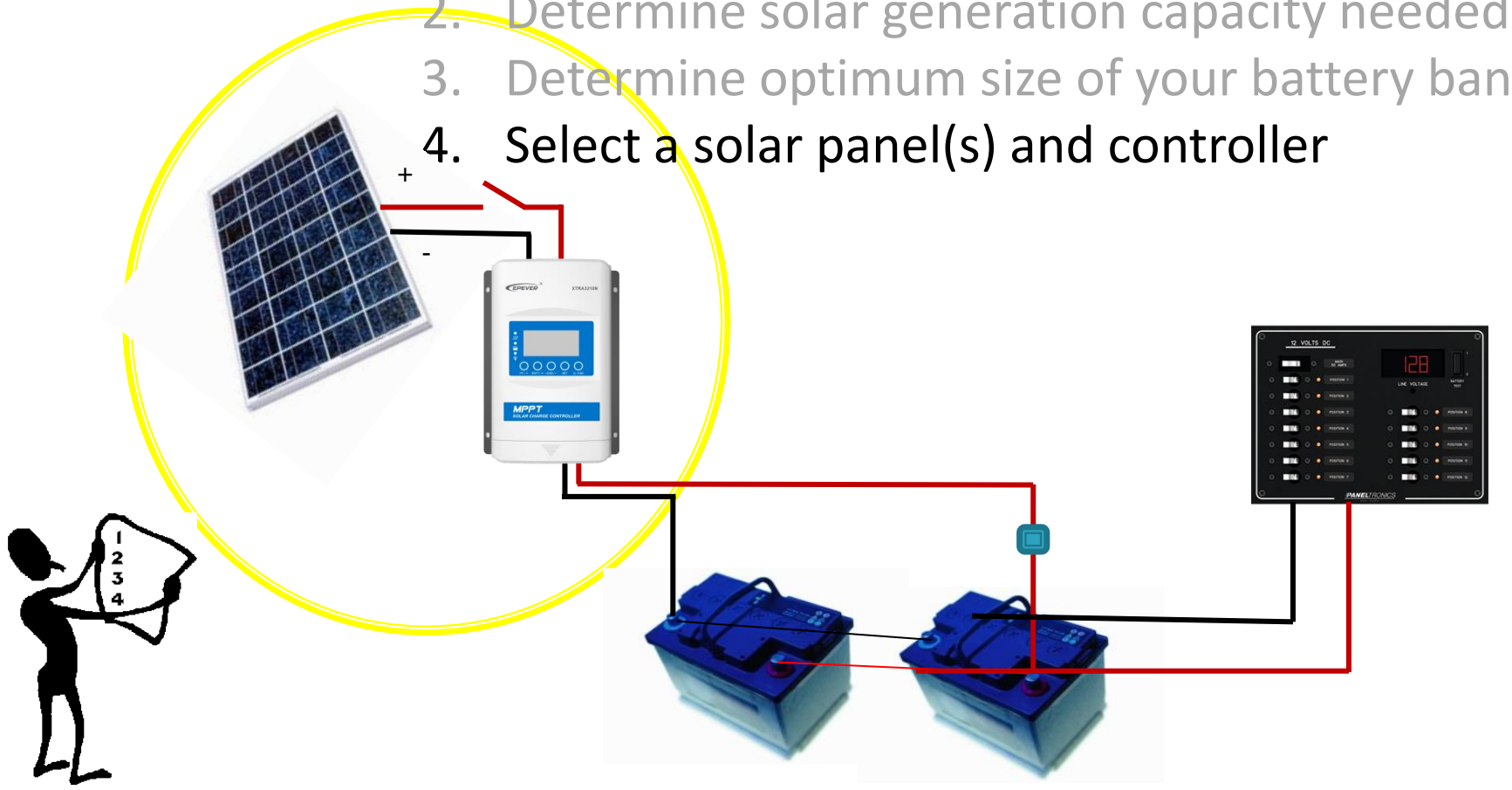
Designing a Solar System to Meet Your Needs

1. Determine daily power consumption
2. Determine solar generation capacity needed
3. Determine optimum size of your battery bank



Designing a Solar System to Meet Your Needs

1. Determine daily power consumption
2. Determine solar generation capacity needed
3. Determine optimum size of your battery bank
4. Select a solar panel(s) and controller



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Sample Power Consumption Worksheet

Appliance	Amps	Hours at Anchor	Hours on Passage	Daily AH * at Anchor	Daily AH on Passage
Refrigeration	5	8	8	40	40
Radar	4		4	0	16
Computer - Laptop	3	1	10	3	30
Autopilot	4		10	0	40
Cabin Lights (LED)	1	4		4	0
Nav/Anchor Lights	0.2	10	10	2	2
Stereo	1	3	3	3	3
VHF Radio	0.5	8	8	4	4
Instruments	1		8	0	8
Pressure Water	6	0.25	0.1	1.5	0.6
Phone Charger	1	2	2	2	2
Other				0	0
Other				0	0
Total Amp Hours				**59.5**	**145.6**

* AH – Amp Hours

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Amp Draw of Each Appliance

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Hours Used of Each Appliance

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Amps X Hours = Daily Amp Hours

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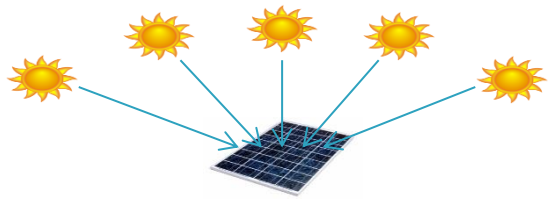
Instruments	1		8	0	8
Pressure Water	6	0.25	0.1	1.5	0.6
Phone Charger	1	2	2	2	2
Other				0	0
Other				0	0
Total Amp Hours				**59.5**	**145.6**
Equipment going through an Inverter (Multiply by 1.2 for inverter inefficiency)					
Microwave	80	0.1		9.6	0
Windlass **				0	0
Other				0	0
Other				0	0
Total Amp Hours				**9.6**	**0**
Total Amp Hours Consumed per Day				**69.1**	**145.6**

Determine Solar Capacity Needed

Step 2

		At Anchor	On Passage
Total Amp Hours Consumed per Day		**69.1**	**145.6**
Battery Charging Voltage	14		
Watt Hours per Day to Replenish Battery Bank		**967.4**	**2,038.4**

Note: Average hours of sun per day is based on the sun angle throughout the day.
Note: 5 is a good number for horizontal panels, 7 for panels with tilt & rotate



PV Solar Panel Capacity Analysis			
Average Hours of Sun per Day	5		
Watts per Day of Solar to Replenish Battery Bank		**193.5**	**407.7**

Watts of Solar Power Required

Watts = Volts x Amps

Sample Power Consumption Worksheet

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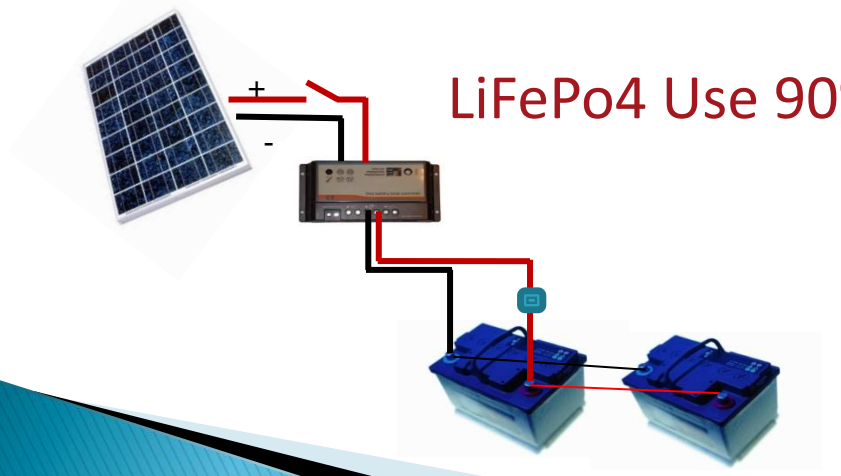
Instruments	1		8	0	8
Pressure Water	6	0.25	0.1	1.5	0.6
Phone Charger	1	2	2	2	2
Other				0	0
Other				0	0
Total Amp Hours				**59.5**	**145.6**
Equipment going through an Inverter (Multiply by 1.2 for inverter inefficiency)					
Microwave	80	0.1		9.6	0
Windlass **				0	0
Other				0	0
Other				0	0
Total Amp Hours				**9.6**	**0**
Total Amp Hours Consumed per Day				**69.1**	**145.6**
* AH - Amp Hours - Amps of current consumed in one hour					
** Windlass is often not considered because engine alternator is running when used					
Battery Charging Voltage			14		
Watt Hours per Day to Replenish Battery Bank				**967.4**	**2,038.4**
PV Solar Panel Capacity Analysis					
Average Hours of Sun per Day			5		
Watts per Day of Solar to Replenish Battery Bank				**193.5**	**407.7**

Available at:
custommarineproducts.com
- Support
  - Manuals & Info

Battery Bank Capacity in our Example

		At Anchor	On Passage
Total Amp Hours Consumed per Day		**69.1**	**145.6**

Amp hours consumed per day		69.1	145.6
Days to run on batteries only	X	2	2
Amp hours required		138.2	291.2
Use 50% of battery bank capacity X 2			
Battery bank capacity needed (amp hours)		**276.4**	**582.4**



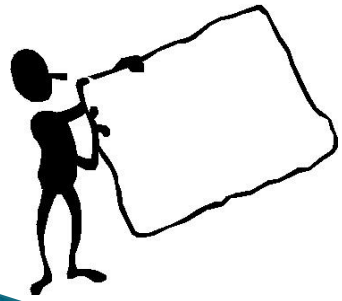
LiFePo4 Use 90% capacity	**154**	**324**

Note: You can use 50% of your battery bank capacity and keep your bank healthy. (lead acid)

Our Findings

Generate All the Power Needed While at Anchor

Power consumption	70 to 145 amp hours
Optimum battery capacity	300 to 600 amp hours (lead acid)
Rated panel wattage needed	200 to 400 watts (roughly)



Watts = Volts x Amps

What Do You Want to Achieve with Your Solar System?

	Solar Array Capacity
A. Keep the batteries charged while on a mooring	**88 Watts**
B. Supplement current power generation capability	**110 Watts**
C. Generate all the power needed while at anchor	**200 Watts**
D. Generate all the power needed on passage and at anchor	**400 Watts**

What Do You Want to Achieve with Your Solar System? Step 4

	Scenarios			
	A	**B**	**C**	**D**
Amp Hrs Consumed per Day	30	69	69	146
Days at Anchor	1	3	3	1
Amp Hrs Required	30	207	207	146
Battery Bank Rated Amp Hrs.	240	240	240	240
Battery Draw Down %	0%	40%	0%	0%
Battery Amps Drawn	-	96	-	-
Amp Hr. Deficit	30	111	207	146
Amp Hr. Deficit per Day	30	37	69	146
Watt Hr. Deficit per Day	420	518	967	2,044
Average Hours of Sun per Day	5.0	5.0	5.0	5.0
Watts per Day of Solar Req'd	**84**	**103.6**	**193.5**	**408.8**

A. Keep the batteries charged while on a mooring
B. Supplement current power generation capability
C. Generate all the power needed while at anchor
D. Generate all the power needed on passage and at anchor

Selecting a Solar Controller

Step 4

	A	B	C	D
Watts per Day of Solar Req'd	**84**	**103.6**	**193.5**	**408.8**
With MPPT Controller				
Watts of Solar Needed	**88.2**	**108.8**	**203.2**	**429.2**
With PWM Controller				
Solar Panel Voltage (Vmp)	20.0	20.0	20.0	20.0
Solar Panel Amps (Imp)	6.0	7.4	13.8	29.2
Watts of Solar Needed	**120**	**148**	**276**	**584**

+ 5%

PWM Controller

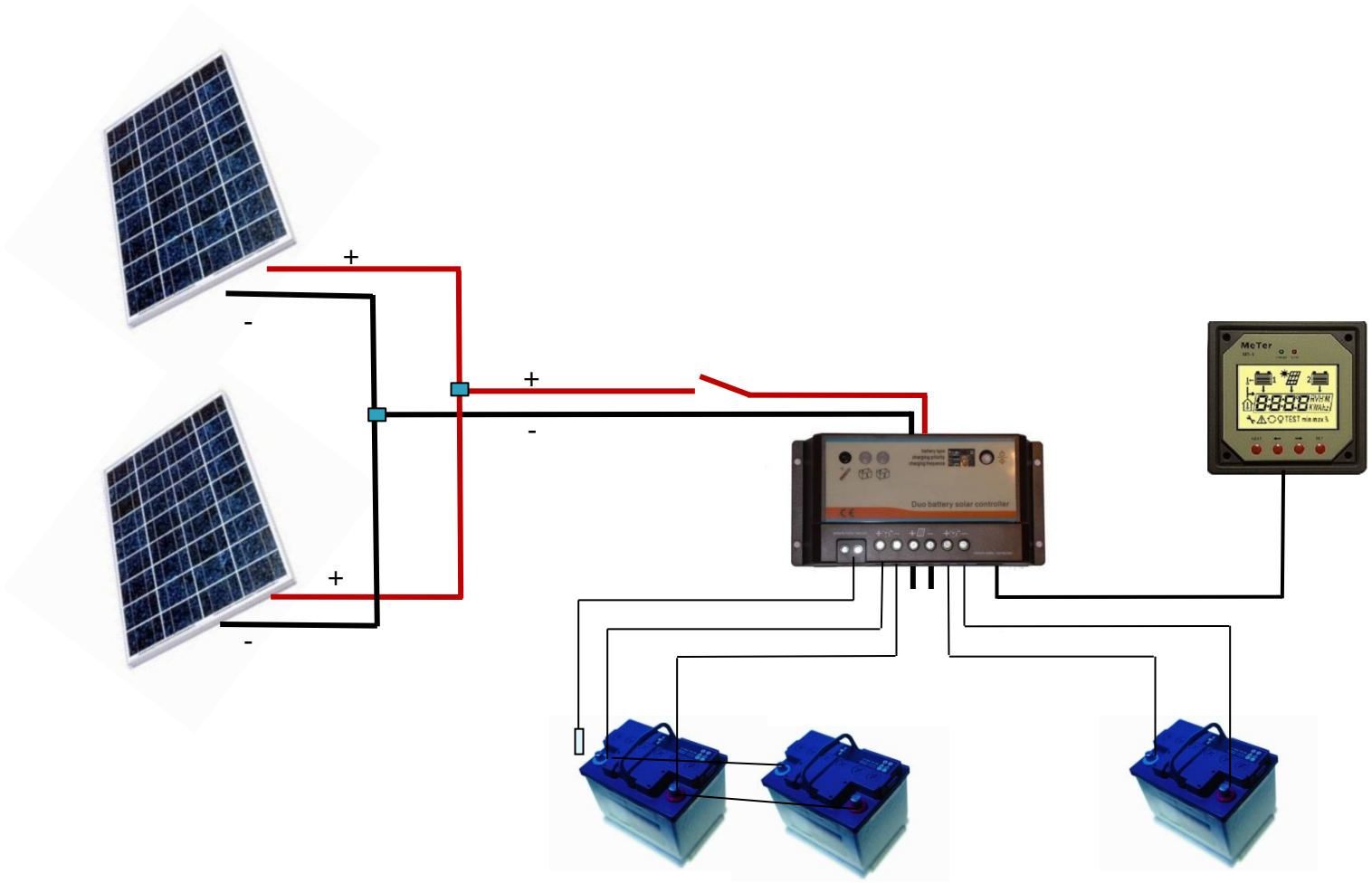
- If solar array is 20 Volts (Vmp) or less
- If solar array is 100 watts or less

MPPT Controller

- If solar array is greater than 18 volts
- If solar array is greater than 100 watts

Note: solar watts / 13V = amp capacity
203.2 W / 13 V = 15.6 A use a 20 amp controller

A Complete and Balanced Solar Power System



Power Consumption Worksheet with PV Solar Panel Sizing

Daily Power Consumption Analysis

Appliance	Amps	Hours at Anchor	Hours on Passage	Daily AH * at Anchor	Daily AH on Passage
Refrigeration	5	8	8	40	40
Radar	4		4	0	16
Computer - Laptop	3	1	10	3	30
Autopilot	4		10	0	40
Cabin Lights (LED)	1	4		4	0
Nav/Anchor Lights	0.2	10	10	2	2
Stereo	1	3	3	3	3
VHF Radio	0.5	8	8	4	4
Instruments	1		8	0	8
Pressure Water	6	0.25	0.1	1.5	0.6
Phone Charger	1	2	2	2	2
Other				0	0
Other				0	0
Total Amp Hours				**59.5**	**145.6**
Equipment going through an Inverter (Multiply by 1.2 for inverter inefficiency)					
Microwave	80	0.1		9.6	0
Windlass **				0	0
Other				0	0
Other				0	0
Total Amp Hours				**9.6**	**0**
Total Amp Hours Consumed per Day				**69.1**	**145.6**

* AH - Amp Hours - Amps of current consumed in one hour

** Windlass is often not considered because engine alternator is running when used

Battery Charging Voltage	14		
Watt Hours per Day to Replenish Battery Bank		**967.4**	**2,038.4**

PV Solar Panel Capacity Analysis

Average Hours of Sun per Day	5		
Watts per Day of Solar to Replenish Battery Bank		**193.5**	**407.7**

Note: 5 is a good number for horizontal panels, 7 for panels with tilt & rotate

Solar Panel Capacity (Watts) Calculation - 4 Scenarios

	Scenarios A	B	C	D
Amp Hrs Consumed per Day	30	69	69	146
Days at Anchor	1	3	3	1
Amp Hrs Required	30	207	207	146
Battery Bank Rated Amp Hrs.	240	240	240	240
Battery Draw Down %	0%	40%	0%	0%
Battery Amps Drawn	-	96	-	-
Amp Hr. Deficit	30	111	207	146
Amp Hr. Deficit per Day	30	37	69	146
Watt Hr. Deficit per Day	420	518	967	2,044
Average Hours of Sun per Day	5.0	5.0	5.0	5.0
Watts per Day of Solar Req'd	**84**	**103.6**	**193.5**	**408.8**
With MPPT Controller				
Watts of Solar Needed	**88.2**	**108.8**	**203.2**	**429.2**
With PWM Controller				
Solar Panel Voltage (Vmp)	20.0	20.0	20.0	20.0
Solar Panel Amps (Imp)	6.0	7.4	13.8	29.2
Watts of Solar Needed	**120**	**148**	**276**	**584**

Scenarios

A. On a mooring with refrigeration

B. 3 days at anchor supplement with 40% of battery capacity

C. 3 days at anchor with no battery supplement

D. All power from solar with max power usage

1. Determine your daily power consumption
2. Assess your battery capacity
3. Calculate solar capacity required
4. Select solar panel(s) and controller

Custom Marine Products
custommarineproducts.com
info@custommarineproducts.com 248 705-8337

High Performance Marine PV Solar Panel Specifications

Model Part Number	Nominal Peak Power Watts-Wp	Open Circuit Voltage Voc	Short Circuit Current Isc	Nominal Voltage Vmp	Nominal Power Current Imp	Cell Efficiency %	Solar Cell Mfg. & Type	Cell Layout	Panel Size Inches	Weight lbs.	Amp Hrs per Day @ 6 Hrs Sun	
Semi-flexible - Monocrystalline												
CMP23055FW	55	23.4	3.1	19.8	2.9	22.0	SunPower	4 x 8	21.25x22.8	3.3	25.4	*
CMP23055FB	55	23.4	3.1	19.8	2.9	22.0	SunPower	4 x 8	21.25x22.8	3.3	25.4	*
CMP23070F	70	23.4	3.9	19.8	3.6	22.8	SunPower	4 x 5	21.25x27.75	3.8	32.3	*
CMP23110F	110	23.4	6.0	19.8	5.6	23.2	SunPower	4 x 8	21.25x42.3	5.8	50.8	*
CMP23120F	120	24.0	6.5	20.0	6.0	20.4	SunPower	4 x 10	22.0x52.25	6.1	55.4	*
CMP23130F	130	26.3	6.2	22.3	5.8	23.7	SunPower	4 x 9	21.25x47.25	5.2	60.0	*
CMP23145F	145	27.8	6.8	23.2	6.3	23.7	SunPower	4 x 10	21.25x52.4	6.6	66.9	*
Rigid - Monocrystalline												
CMP22100S	100	21.9	6.8	18.6	5.8	20.2	SunPower	4 x 8	21.3x41.7	20.3	46.2	*
CMP22140S	140	29.3	6.1	24.8	5.7	23.7	SunPower	5 x 8	26.8x41.7	22.0	64.6	*
CMP22150SR	150	29.3	7.0	24.8	6.5	23.7	SunPower	4 x 12	21.3x56.9	26.5	69.2	*
CMP22175S	175	36.4	6.3	30.3	5.8	22.8	SunPower	7 x 7	36.2x37	26.5	80.8	*
CMP21105M	105	21.6	6.5	17.5	6.0	17.9	Bosch	4 x 6	26.4x39.4	18.0	36.0	
Rigid - Polycrystalline												
CMP21100P	100	21.6	6.2	17.5	5.7	16.7	Q Cell	4 x 6	26.4x39.4	18.0	34.3	
CMP21150P	150	21.9	9.2	17.6	8.5	17.1	Q Cell	6 x 6	39x39.5	26.5	51.0	
CMP21160PK	160	21.9	9.7	17.6	9.0	18.0	Q Cell	4 x 9	26.3x59	26.5	54.0	

Semi-flexible SunPower Cells

Rigid Polycrystalline

Rigid Monocrystalline

Selecting the Proper Solar System for Your Boat

Q & A

Tom Trimmer
Custom Marine Products

Solar Panel Installation Ideas

Semi-Flexible Solar Panels

- Canvas biminis
- Hard tops

Rigid Solar Panels

- Canvas biminis
- Hard tops
- Top-of-pole systems
- Dinghy davits

See **Gallery of Installations** at custommarineproducts.com for more ideas.

100 Watt Semi-flexible Panels Zippered On

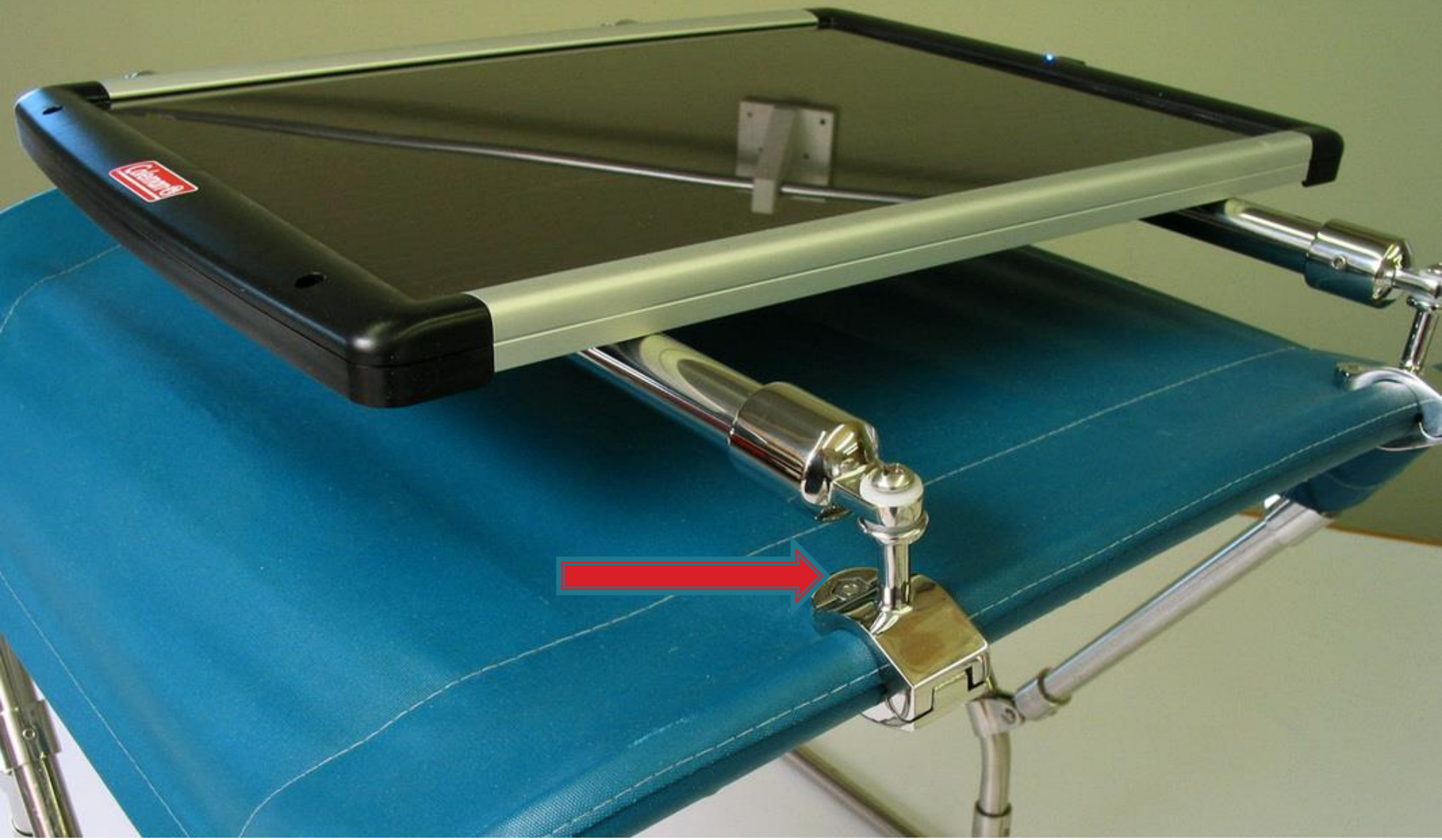
Two 50 Watt Semi-flexible Panels Bolted On

Four 100 Watt Semi-flexible Panels Sewn On

Six 100 Watt Semi-flexible Panels Sewn On

Two 110 Watt Semi-flexible Panels Bolted On

110 Watt Semi-flexible Panel Bolted On



Gemini Mounting Bracket

Two Panels on a Bimini Mounted Frame

130 Watt Panel Rotated on a Bar

Three 120 Watt Solar Panels

Three 120 Watt Solar Panels on a Hylas 49

Two Rigid Panels Cantilevered

130 Watt Rigid Panel on a Ranger Tug 32

Two 275 Watt Panels on the Pilot House of a Nordic Tug 37

Four 100 Watt Rigid Panels on a Nordic Tug 32

175 Watt Panel on a Pole with Outboard Motor Crane Tilt and Rotate

130 Watt Panel on a Pole Mount – Morgan 38

Two 90 Watt Panels
Pole Mounted

Two 100 Watt Panels
Rotatable On Dinghy Davits