SOLAR MICROGRIDS:

SOLAR & ENERGY STORAGE FOR OFF GRID APPLICATIONS

Joe O’Connor

January 2018

SUMMARY

- About Joe O’Connor
- Why solar as an energy source?
- Why lithium batteries for energy storage?
- Defining Microgrids
- Case study: Virunga National Park, in The Congo with GivePower

Sollega™

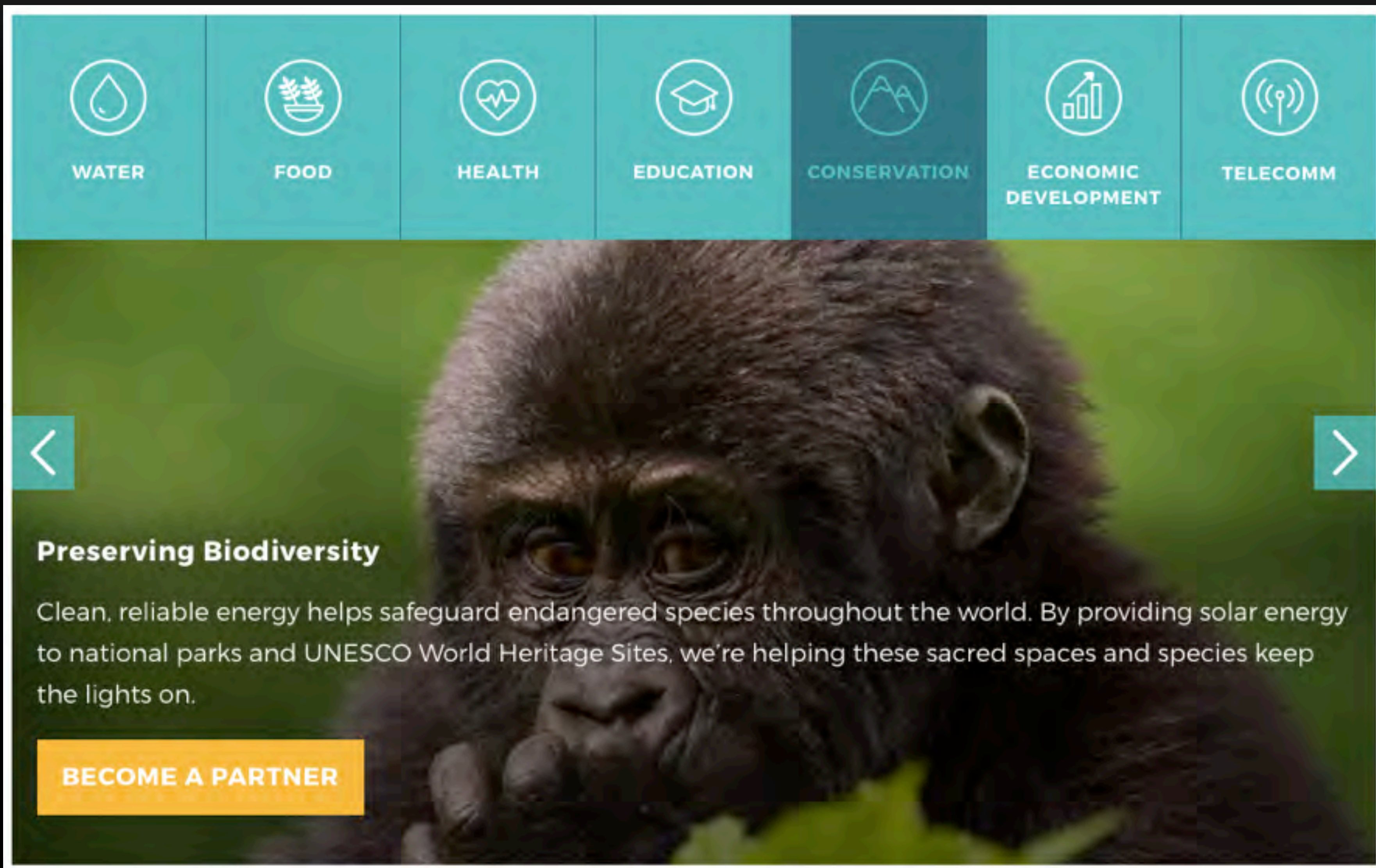
The Simple Solar Racking Solution™

SolarCity

Zep Solar

Mercedes-Benz Energy


HAITI
KENYA
NEPAL
NICARAGUA
CONGO

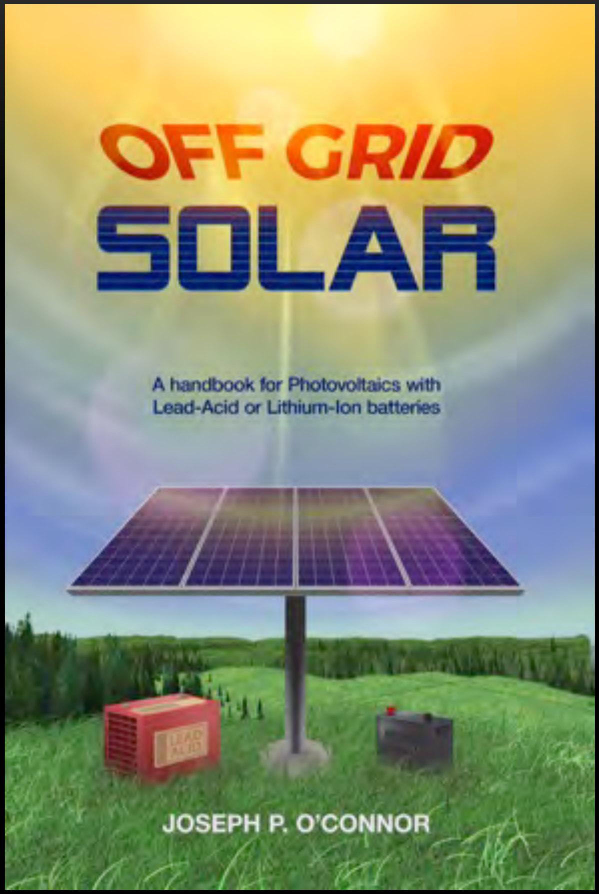

WATER
FOOD
HEALTH
EDUCATION
CONSERVATION
ECONOMIC DEVELOPMENT
TELECOMM
Preserving Biodiversity
Clean, reliable energy helps safeguard endangered species throughout the world. By providing solar energy to national parks and UNESCO World Heritage Sites, we're helping these sacred spaces and species keep the lights on.
BECOME A PARTNER

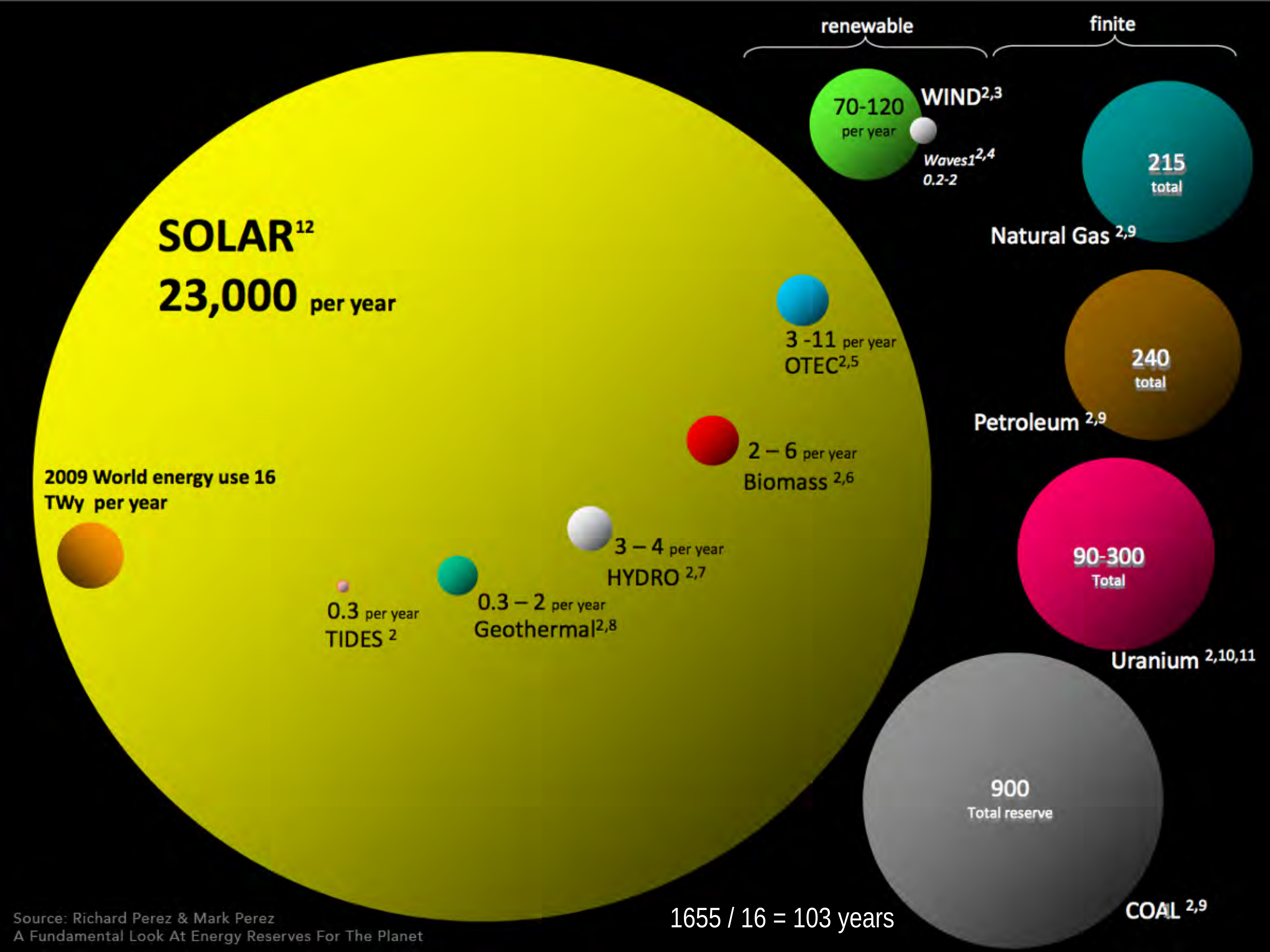
givepower

WHY DID I WRITE THIS BOOK?

The first and only book to focus on:

- Off Grid solar only, eliminating the confusion of grid-tied systems
- Future technologies, primarily Lithium-Ion batteries
- Global audience, using internationally recognized codes and standards





renewable
finite
70-120
per year
WIND[2,3]
Waves1[2,4]
0.2-2
215
total
Natural Gas [2,9]
SOLAR[12]
23,000 per year
3 -11 per year
OTEC[2,5]
240
total
Petroleum [2,9]
2 – 6 per year
Biomass [2,6]
2009 World energy use 16
TWy per year
3 – 4 per year
HYDRO [2,7]
90-300
Total
0.3 – 2 per year
Geothermal[2,8]
0.3 per year
TIDES [2]
Uranium [2,10,11]
900
Total reserve
COAL [2,9]
Source: Richard Perez & Mark Perez
A Fundamental Look At Energy Reserves For The Planet
1655 / 16 = 103 years

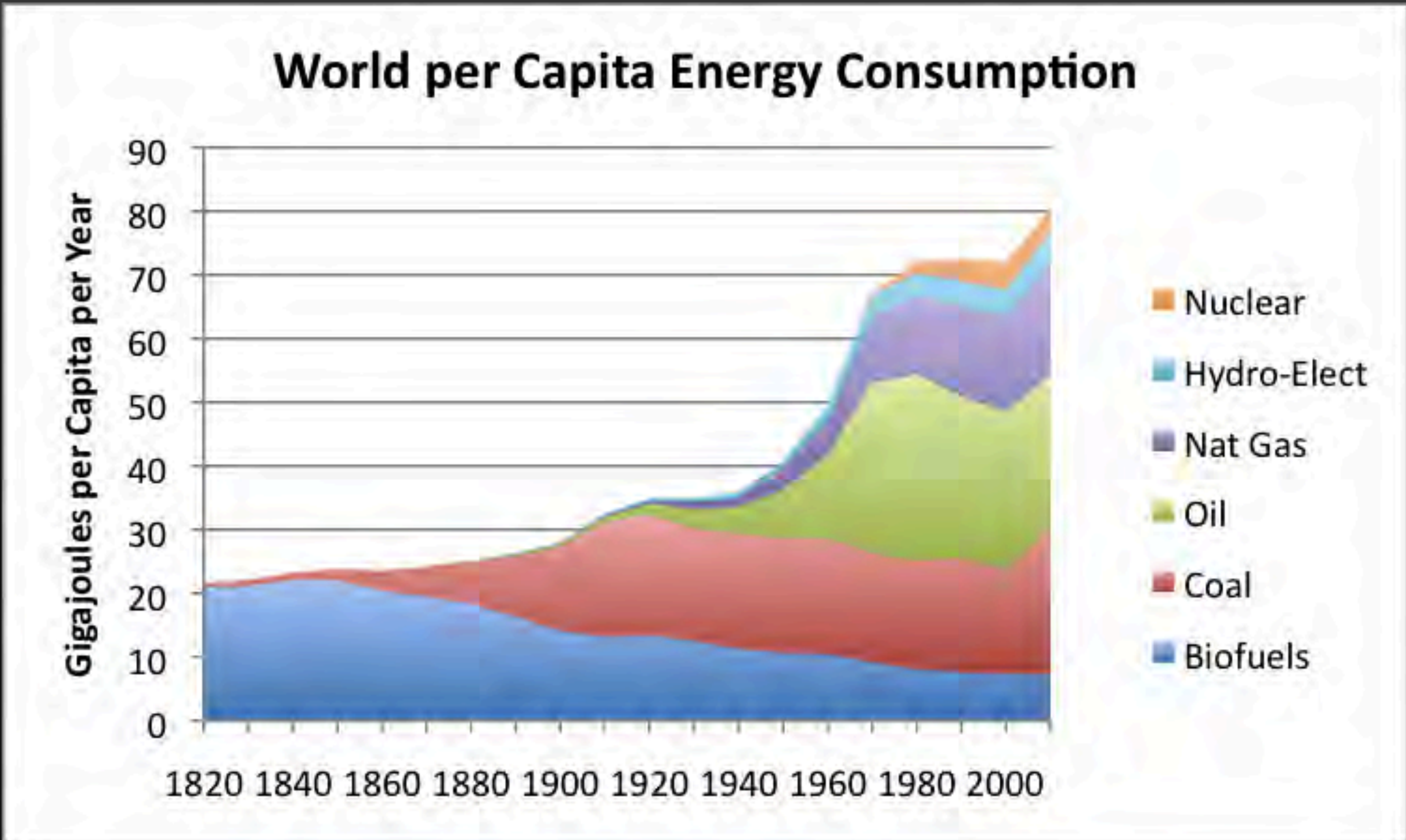
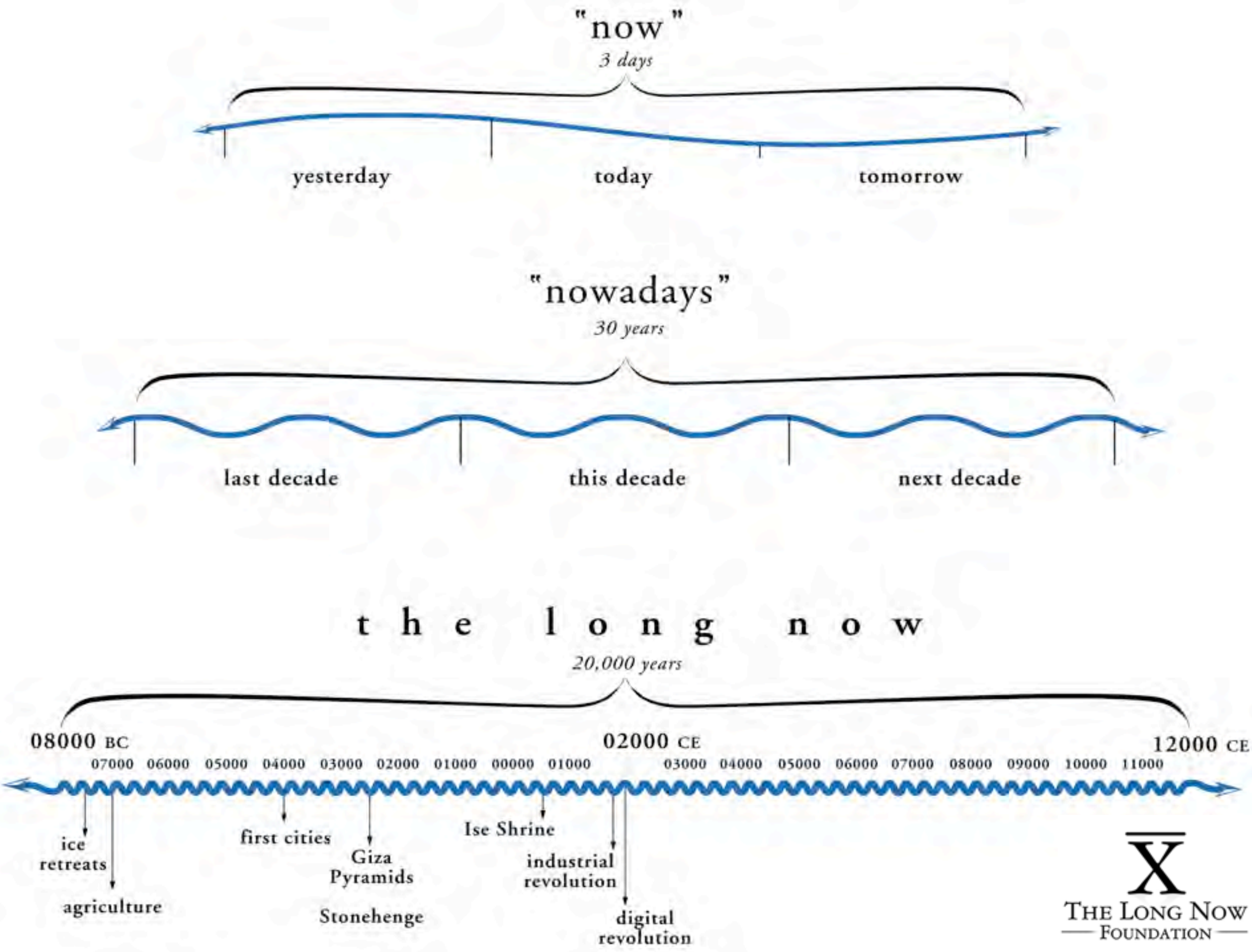


Figure 1. World Energy Consumption by Source, Based on Vaclav Smil estimates from Energy Transitions: History, Requirements and Prospects together with BP Statistical Data for 1965 and subsequent


"now"
3 days
yesterday
today
tomorrow
"nowadays"
30 years
last decade
this decade
next decade
t h e l o n g n o w
20,000 years
08000 BC
02000 CE
12000 CE
07000 06000 05000 04000 03000 02000 01000 00000 01000
03000 04000 05000 06000 07000 08000 09000 10000 11000
ice retreats
agriculture
first cities
Giza Pyramids
Stonehenge
Ise Shrine
industrial revolution
digital revolution
THE LONG NOW FOUNDATION

"If we use our fuel to get our power, we are living on our capital and exhausting it rapidly. This method is barbarous and wantonly wasteful, and will have to be stopped in the interest of coming generations."

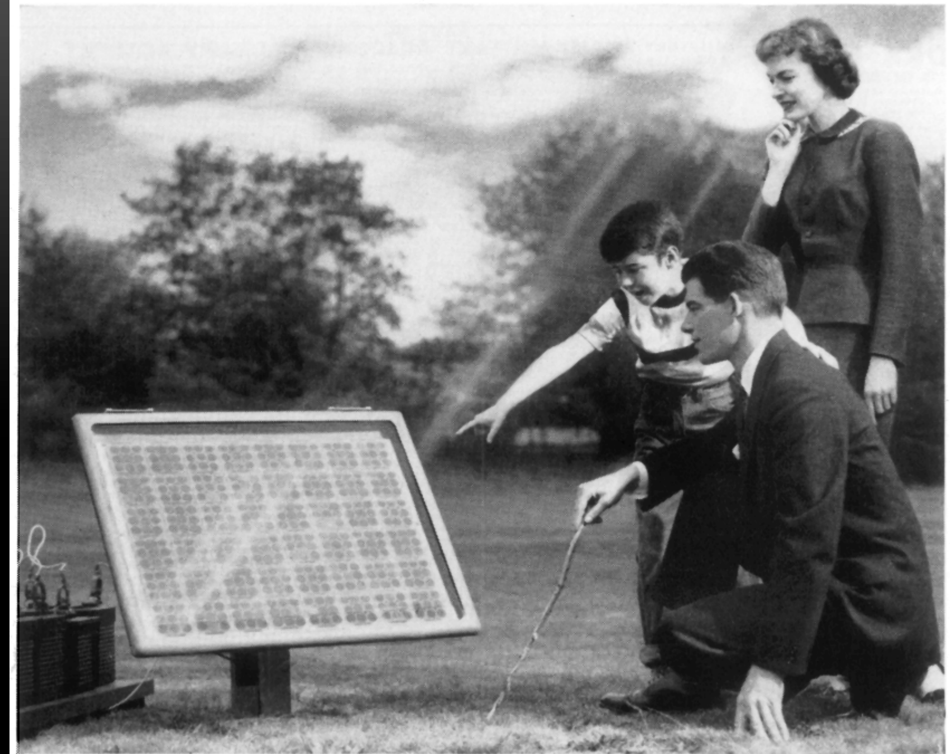
– Nikola Tesla, 1915

"I’d put my money on the sun and solar energy. What a source of power! I hope we don’t have to wait until oil and coal run out before we tackle that. I wish I had more years left!”

– Thomas Edison, 1931

In 1954 Bell Labs exhibited the first high-power silicon PV cell.

“The New York Times forecasts that solar cells will eventually lead to a source of "limitless energy of the sun”.



Something New Under the Sun. It's the Bell Solar Battery, made of thin discs of specially treated silicon, an ingredient of common sand. It converts the sun's rays directly into usable amounts of electricity. Simple and trouble-free. (The storage batteries beside the solar battery store up its electricity for night use.)

Bell System Solar Battery Converts Sun's Rays into Electricity!

Bell Telephone Laboratories invention has great possibilities for telephone service and for all mankind

Ever since Archimedes, men have been searching for the secret of the sun.

For it is known that the same kindly rays that help the flowers and the grains and the fruits to grow also send us almost limitless power. It is nearly as much every three days as in all known reserves of coal, oil and uranium.

If this energy could be put to use – there would be enough to turn every wheel and light every lamp that mankind would ever need.

The dream of ages has been brought closer by the Bell System Solar Battery. It was invented at the Bell Telephone Laboratories after long research and first announced in 1954. Since then its efficiency has been doubled and its usefulness extended.

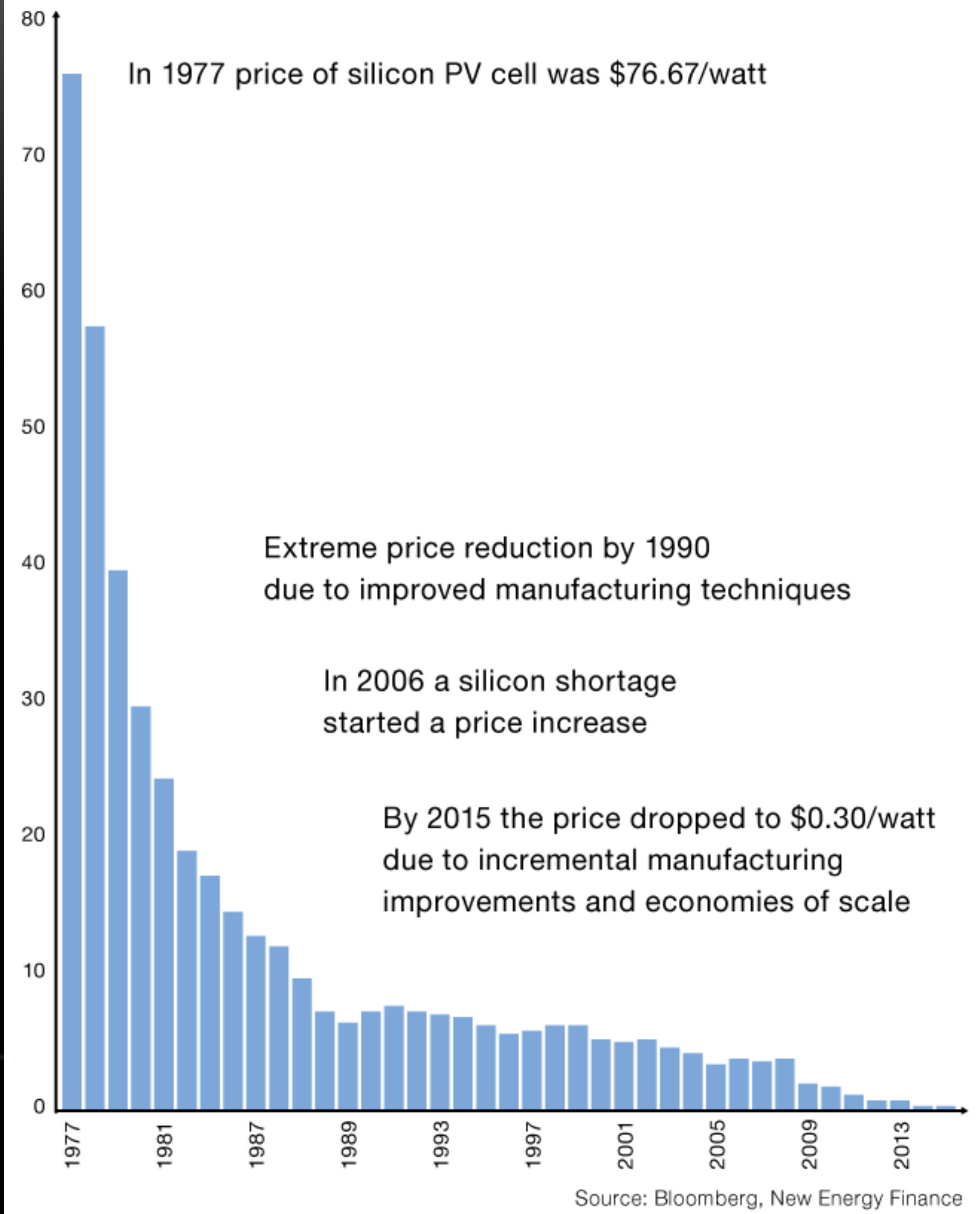
There's still much to be done before the battery's possibilities in telephony and for other uses are fully developed. But a good and pioneering start has been made.

The progress so far is like the opening of a door through which we can glimpse exciting new things for the future. Great benefits for telephone users and for all mankind may come from this forward step in putting the energy of the sun to practical use.

BELL TELEPHONE SYSTEM

"There is no energy crisis, only a crisis of ignorance.

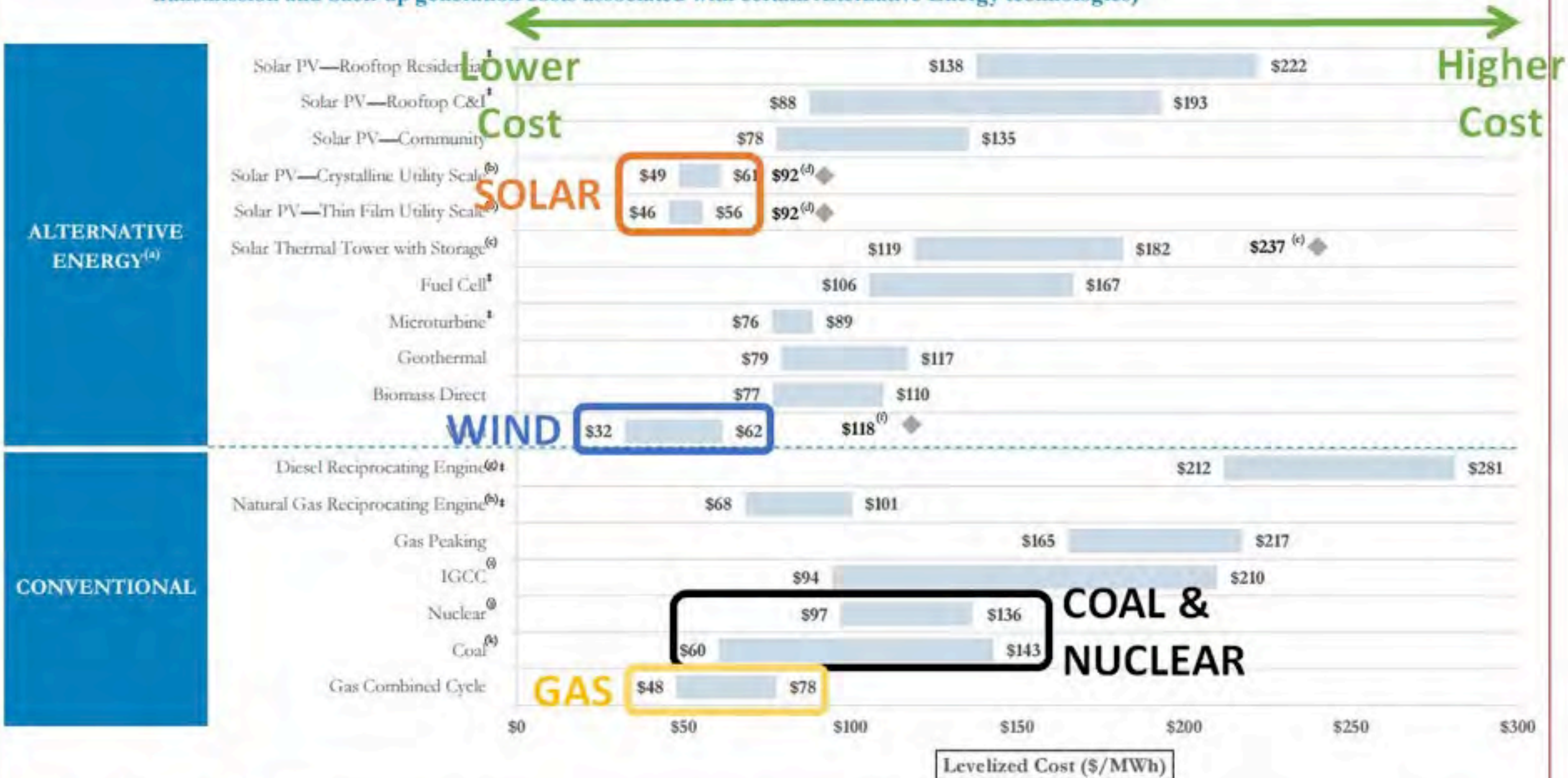
– *Buckminster Fuller, 1969*



In 1977 price of silicon PV cell was $76.67/watt
Extreme price reduction by 1990
due to improved manufacturing techniques
In 2006 a silicon shortage
started a price increase
By 2015 the price dropped to $0.30/watt
due to incremental manufacturing
improvements and economies of scale
80
70
60
50
40
30
20
10
0
1977
1981
1987
1989
1993
1997
2001
2005
2009
2013
Source: Bloomberg, New Energy Finance

Unsubsidized Levelized Cost of Energy Comparison

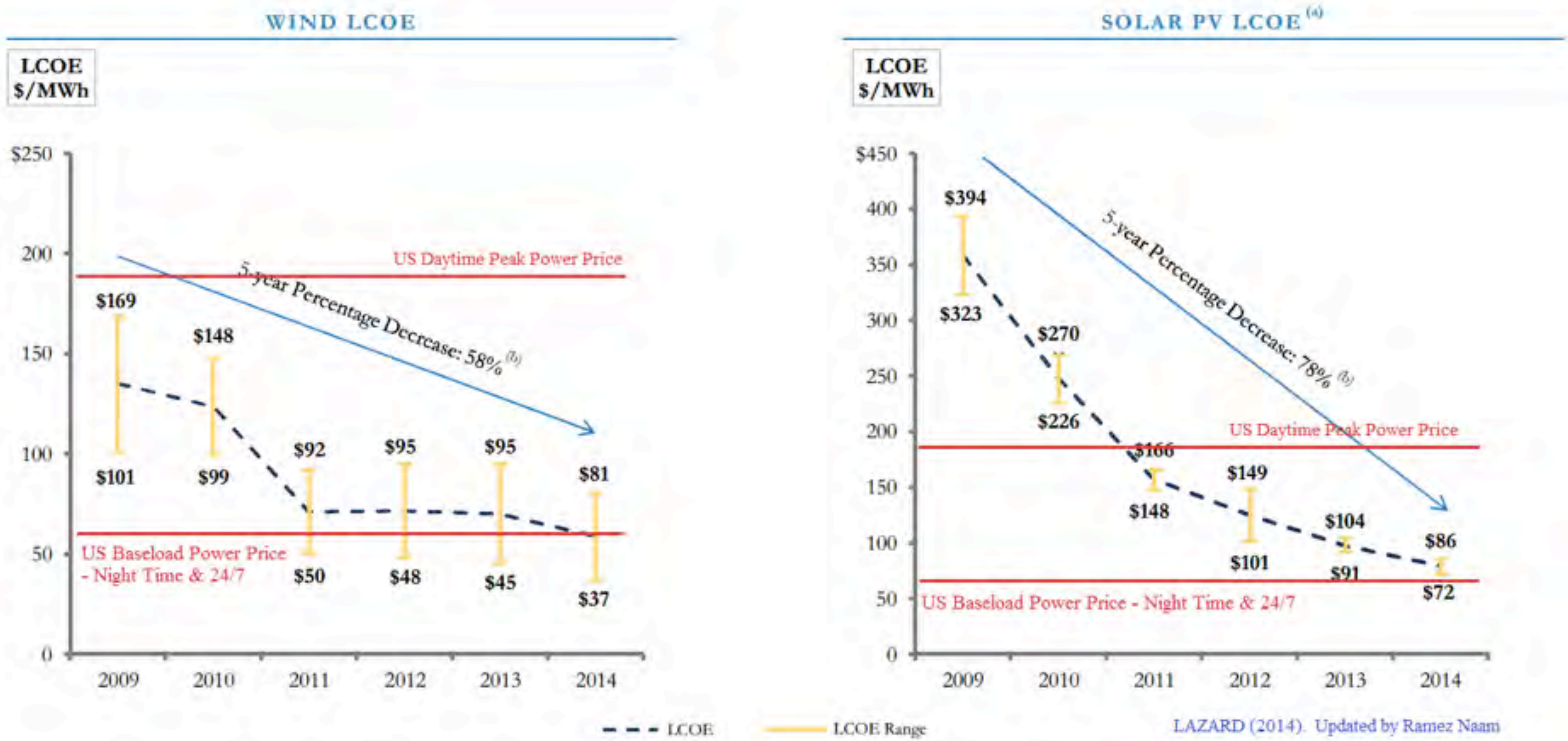
Certain Alternative Energy generation technologies are cost-competitive with conventional generation technologies under some scenarios; such observation does not take into account potential social and environmental externalities (e.g., social costs of distributed generation, environmental consequences of certain conventional generation technologies, etc.), reliability or intermittency-related considerations (e.g., transmission and back-up generation costs associated with certain Alternative Energy technologies)

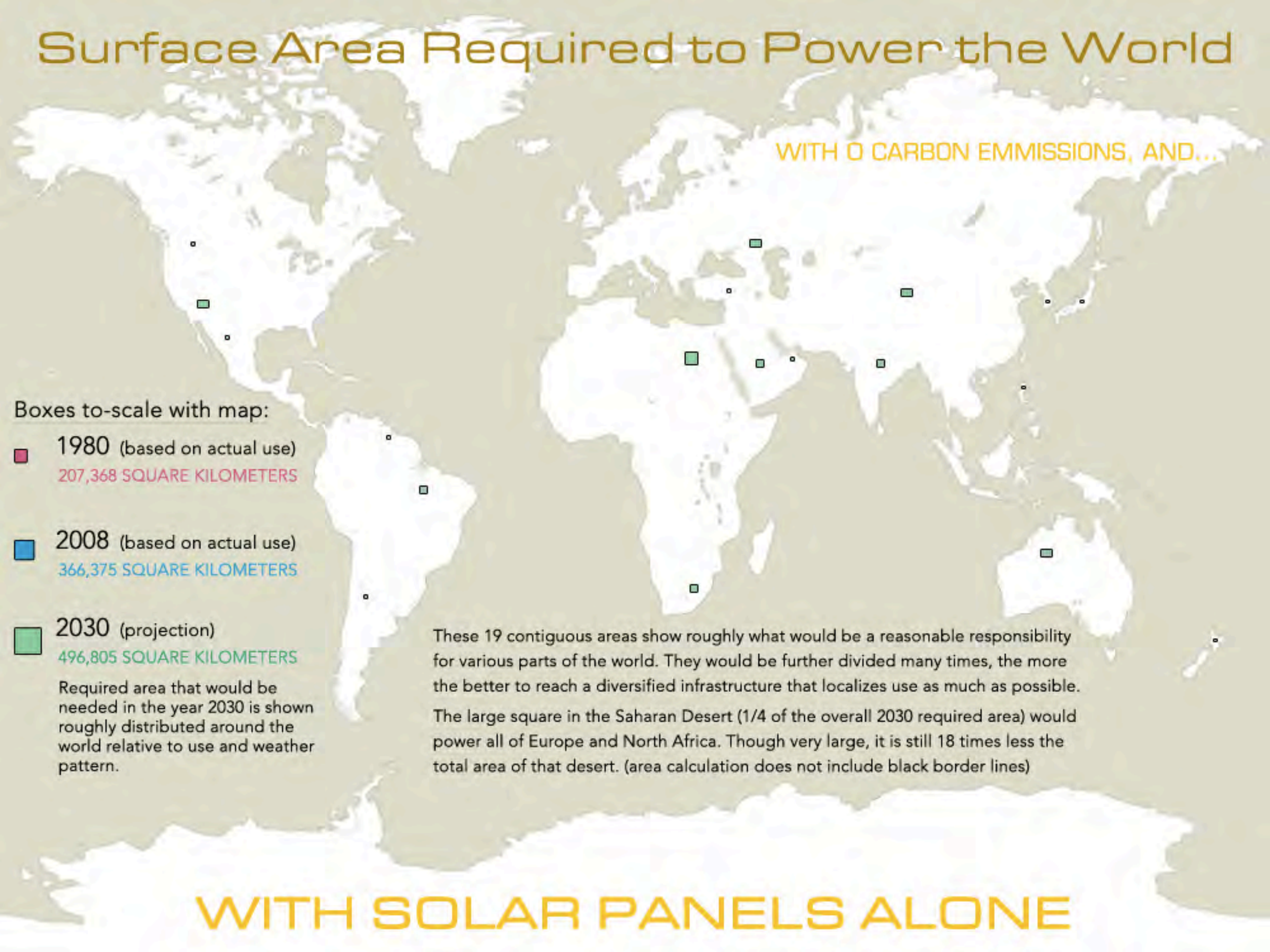


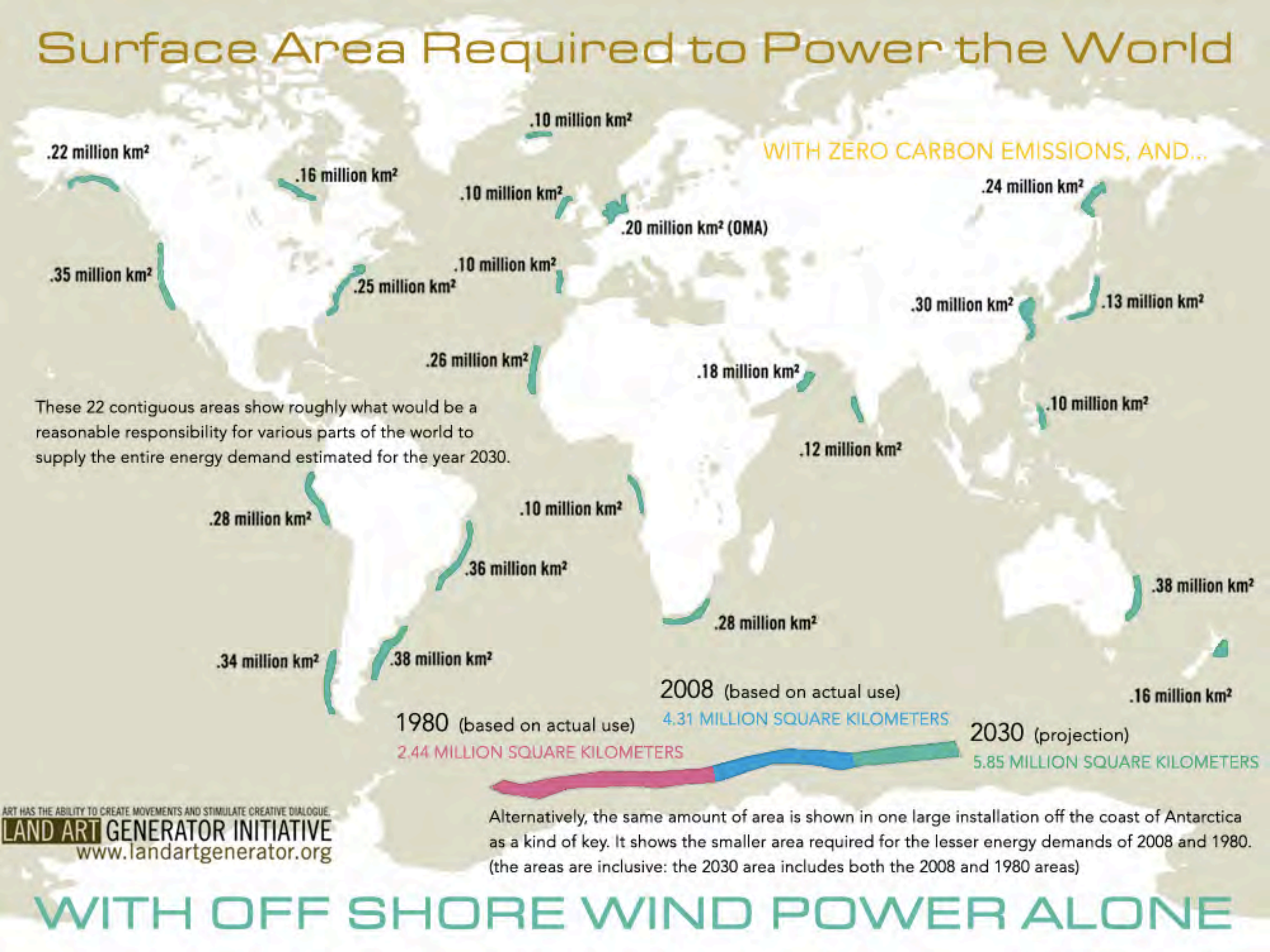
Source: *Lazard estimates.*

Note: Here and throughout this presentation, unless otherwise indicated, analysis assumes 60% debt at 8% interest rate and 40% equity at 12% cost for conventional and Alternative Energy generation technologies. Reflects global, illustrative costs of capital, which may be significantly higher than OECD country costs of capital. See page 15 for additional details on cost of capital. Analysis does not reflect potential impact of recent draft rule to regulate carbon emissions under Section 111(d). See pages 18–20 for fuel costs for each technology. See following page for footnotes.

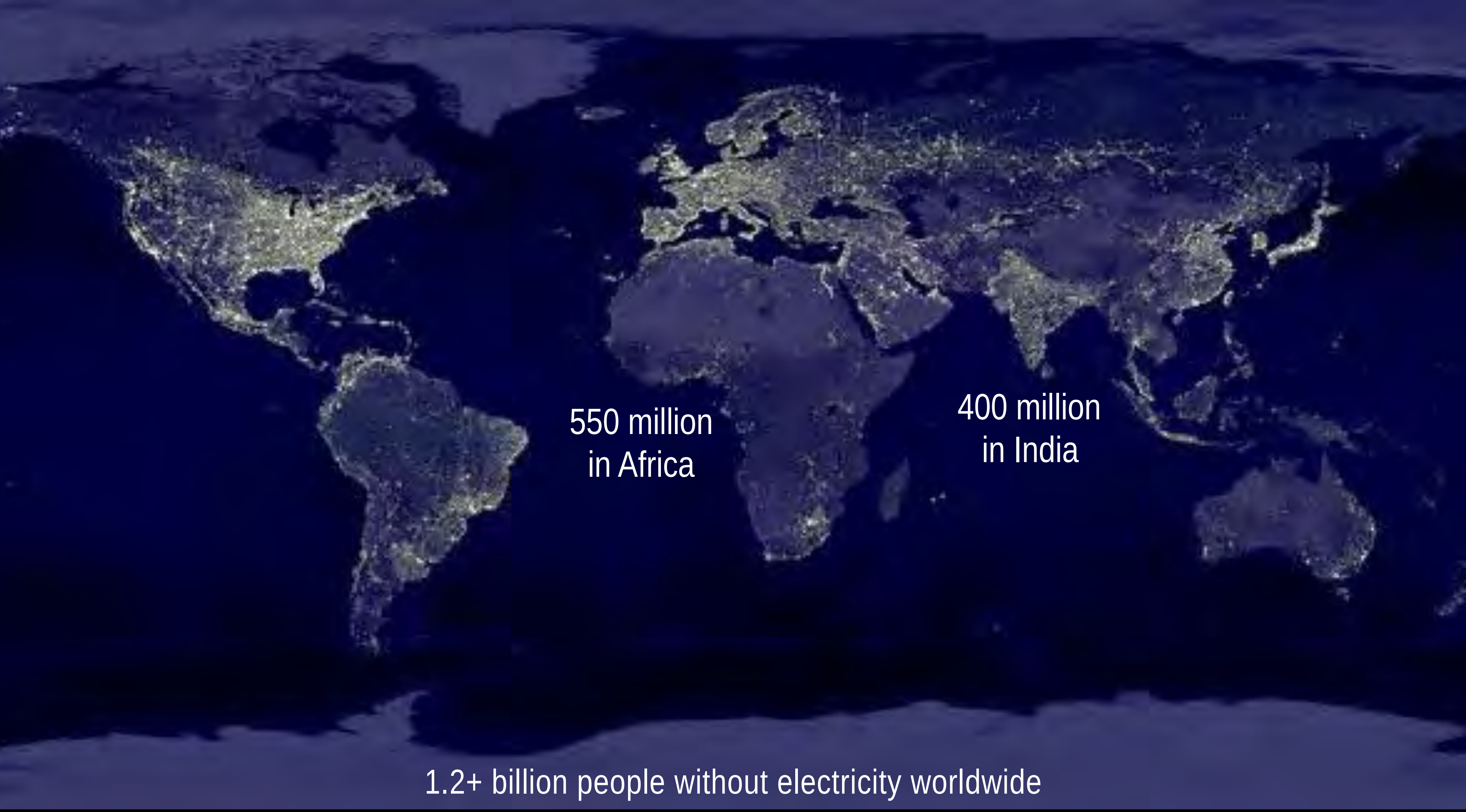
‡ Denotes distributed generation technology.


WIND LCOE
LCOE $/MWh
$250
200
150
100
50
0
US Daytime Peak Power Price
5-year Percentage Decrease: 58% (b)
$169
$148
$101
$99
$92
$95
$95
$81
$50
$48
$45
$37
US Baseload Power Price - Night Time & 24/7
2009
2010
2011
2012
2013
2014
SOLAR PV LCOE (a)
LCOE $/MWh
$450
400
350
300
250
200
150
100
50
0
5-year Percentage Decrease: 78% (b)
$394
$323
$270
$226
$166
$148
$149
$101
$104
$91
$86
$72
US Daytime Peak Power Price
US Baseload Power Price - Night Time & 24/7
LCOE
LCOE Range
LAZARD (2014). Updated by Ramez Naam


Surface Area Required to Power the World
WITH 0 CARBON EMMISSIONS, AND...
Boxes to-scale with map:
1980 (based on actual use)
207,368 SQUARE KILOMETERS
2008 (based on actual use)
366,375 SQUARE KILOMETERS
2030 (projection)
496,805 SQUARE KILOMETERS
Required area that would be needed in the year 2030 is shown roughly distributed around the world relative to use and weather pattern.
These 19 contiguous areas show roughly what would be a reasonable responsibility for various parts of the world. They would be further divided many times, the more the better to reach a diversified infrastructure that localizes use as much as possible.
The large square in the Saharan Desert (1/4 of the overall 2030 required area) would power all of Europe and North Africa. Though very large, it is still 18 times less the total area of that desert. (area calculation does not include black border lines)
WITH SOLAR PANELS ALONE

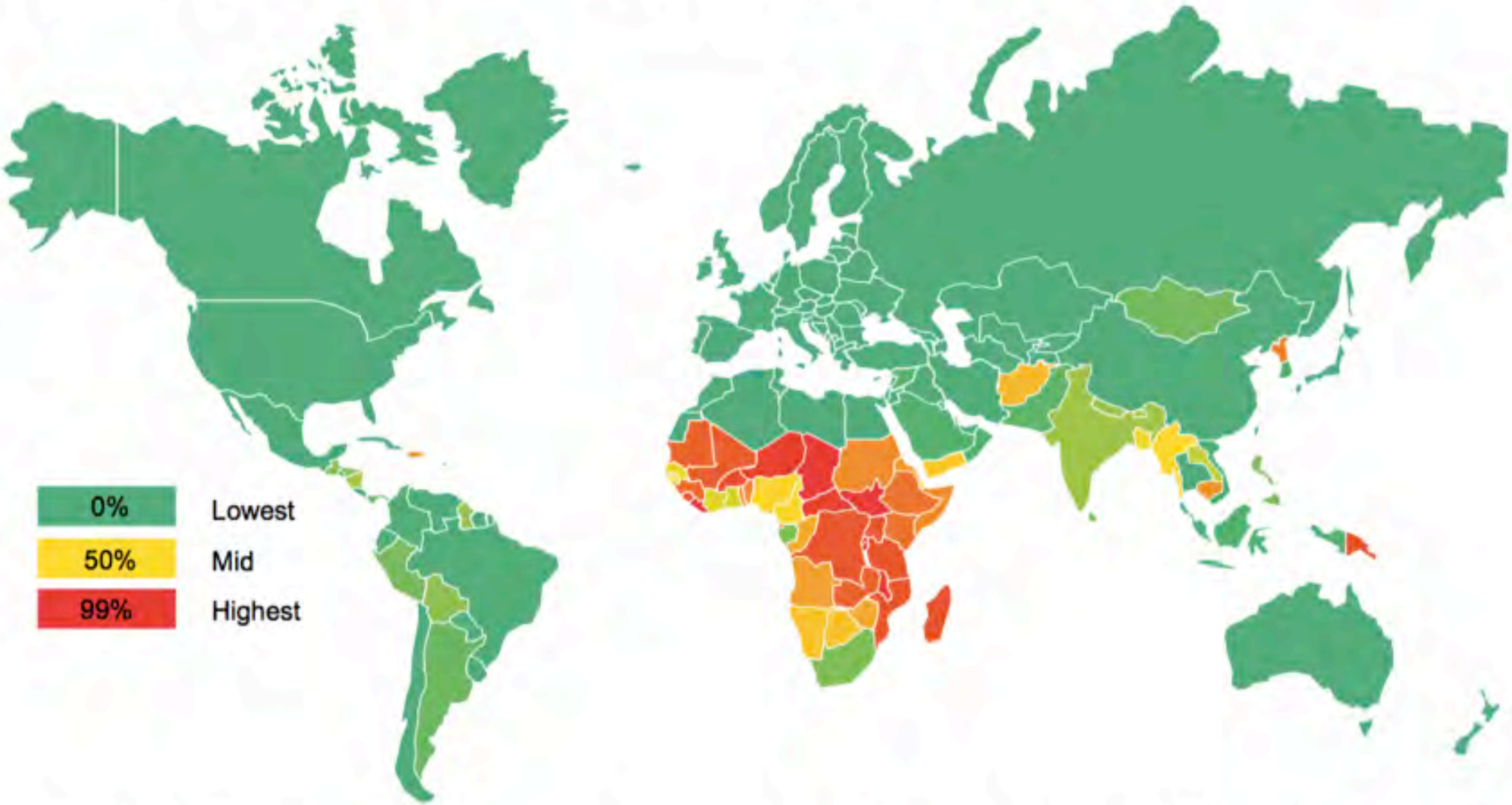


Surface Area Required to Power the World
WITH ZERO CARBON EMISSIONS, AND...
.10 million km²
.22 million km²
.16 million km²
.10 million km²
.20 million km² (OMA)
.24 million km²
.35 million km²
.25 million km²
.10 million km²
.30 million km²
.13 million km²
.26 million km²
.18 million km²
.10 million km²
.12 million km²
These 22 contiguous areas show roughly what would be a reasonable responsibility for various parts of the world to supply the entire energy demand estimated for the year 2030.
.28 million km²
.10 million km²
.36 million km²
.38 million km²
.28 million km²
.34 million km²
.38 million km²
.16 million km²
2008 (based on actual use)
4.31 MILLION SQUARE KILOMETERS
1980 (based on actual use)
2.44 MILLION SQUARE KILOMETERS
2030 (projection)
5.85 MILLION SQUARE KILOMETERS
ART HAS THE ABILITY TO CREATE MOVEMENTS AND STIMULATE CREATIVE DIALOGUE.
LAND ART GENERATOR INITIATIVE
www.landartgenerator.org
Alternatively, the same amount of area is shown in one large installation off the coast of Antarctica as a kind of key. It shows the smaller area required for the lesser energy demands of 2008 and 1980. (the areas are inclusive: the 2030 area includes both the 2008 and 1980 areas)
WITH OFF SHORE WIND POWER ALONE

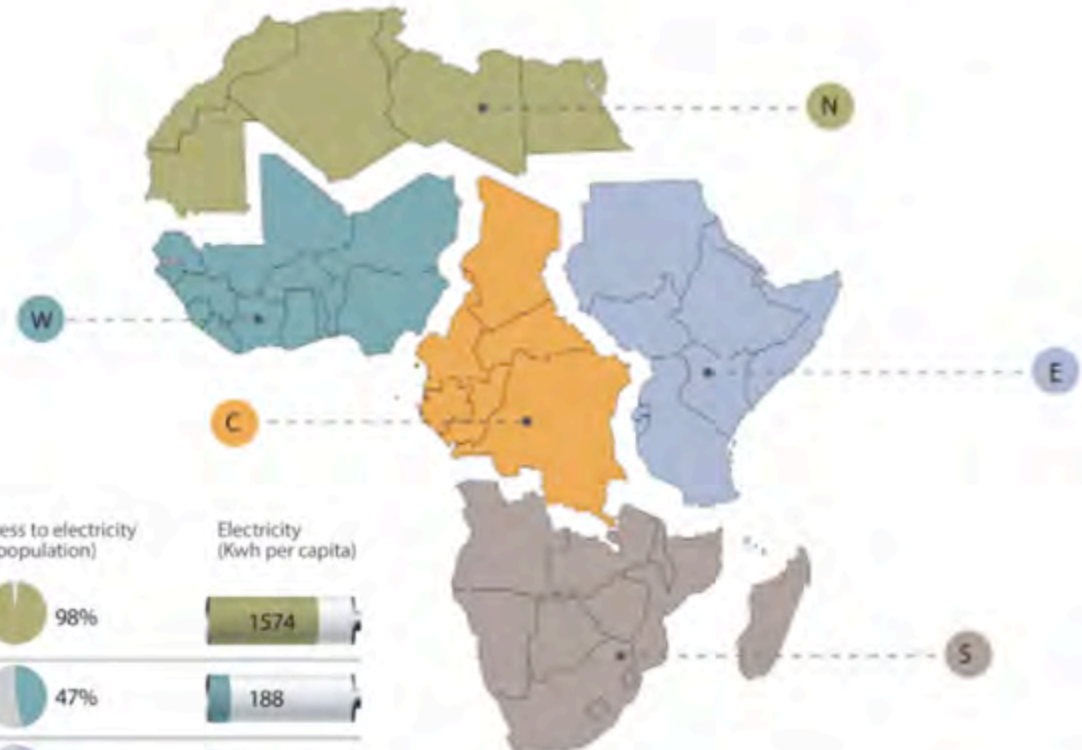


RURAL ELECTRIFICATION

Figure 1: Share of population without grid access (percent of total)



Source: World Bank, Bloomberg New Energy Finance. Note: Figures refer to 2012 data.



		Population (million people)	GDP billion/yr (current international $)	Access to electricity (% population)	Electricity (Kwh per capita)
N	North Africa	175	1936	98%	1574
W	West Africa	327	1310	47%	188
E	East Africa	303	646	23%	91
C	Central Africa	115	227	25%	167
S	Southern Africa	177	1100	43%	2061

Source: Remap 2030, IRENA 2015

"The 1.2 billion people living without access to the power grid spend about $27 billion annually on lighting and mobile-phone charging with kerosene, candles, battery torches or other fossil-fuel powered stopgap technologies."

—*Off-Grid Solar Market Trends Report 2016, Bloomberg New Energy Finance and Lighting Global.*

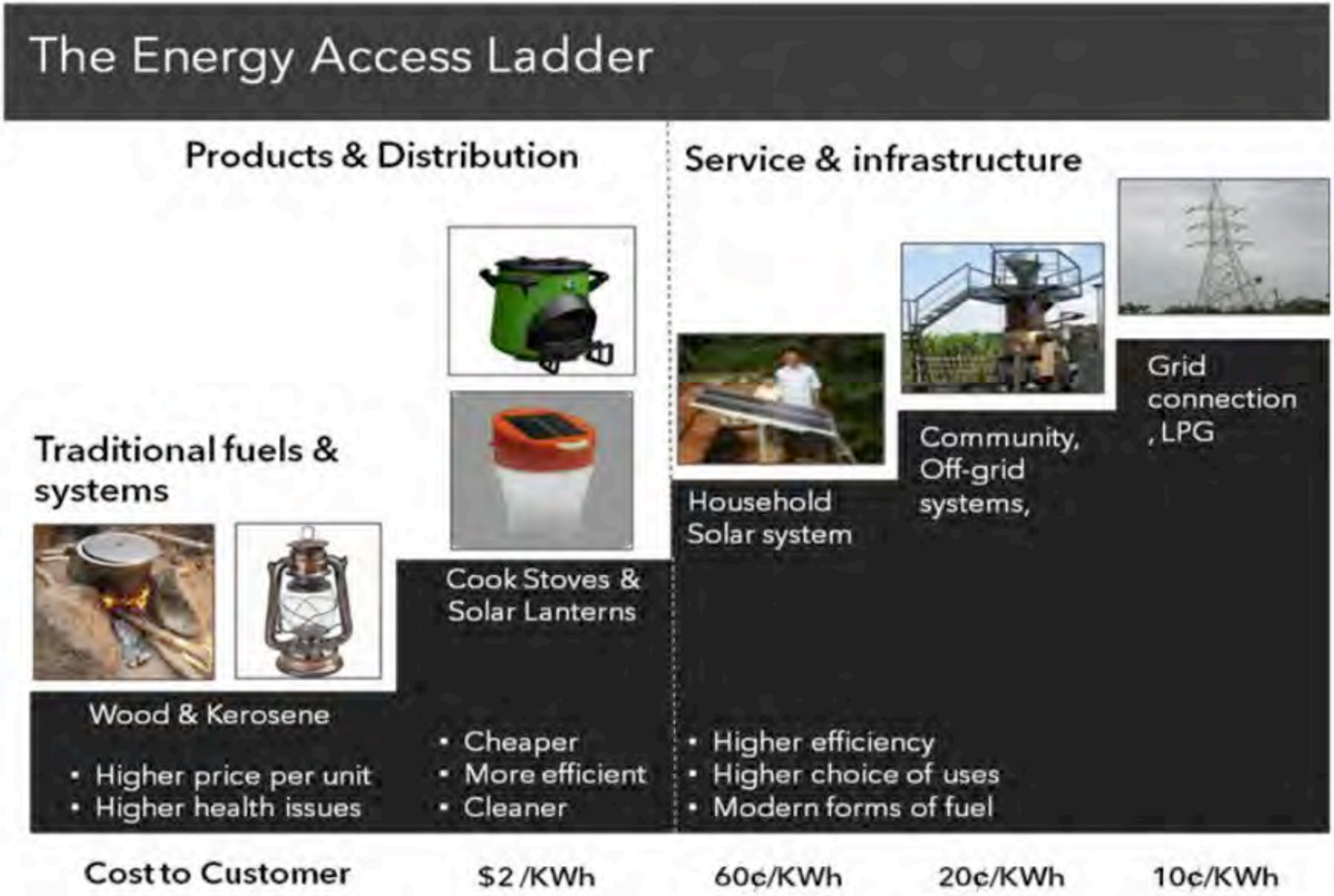


Figure 8: Energy Access Ladder

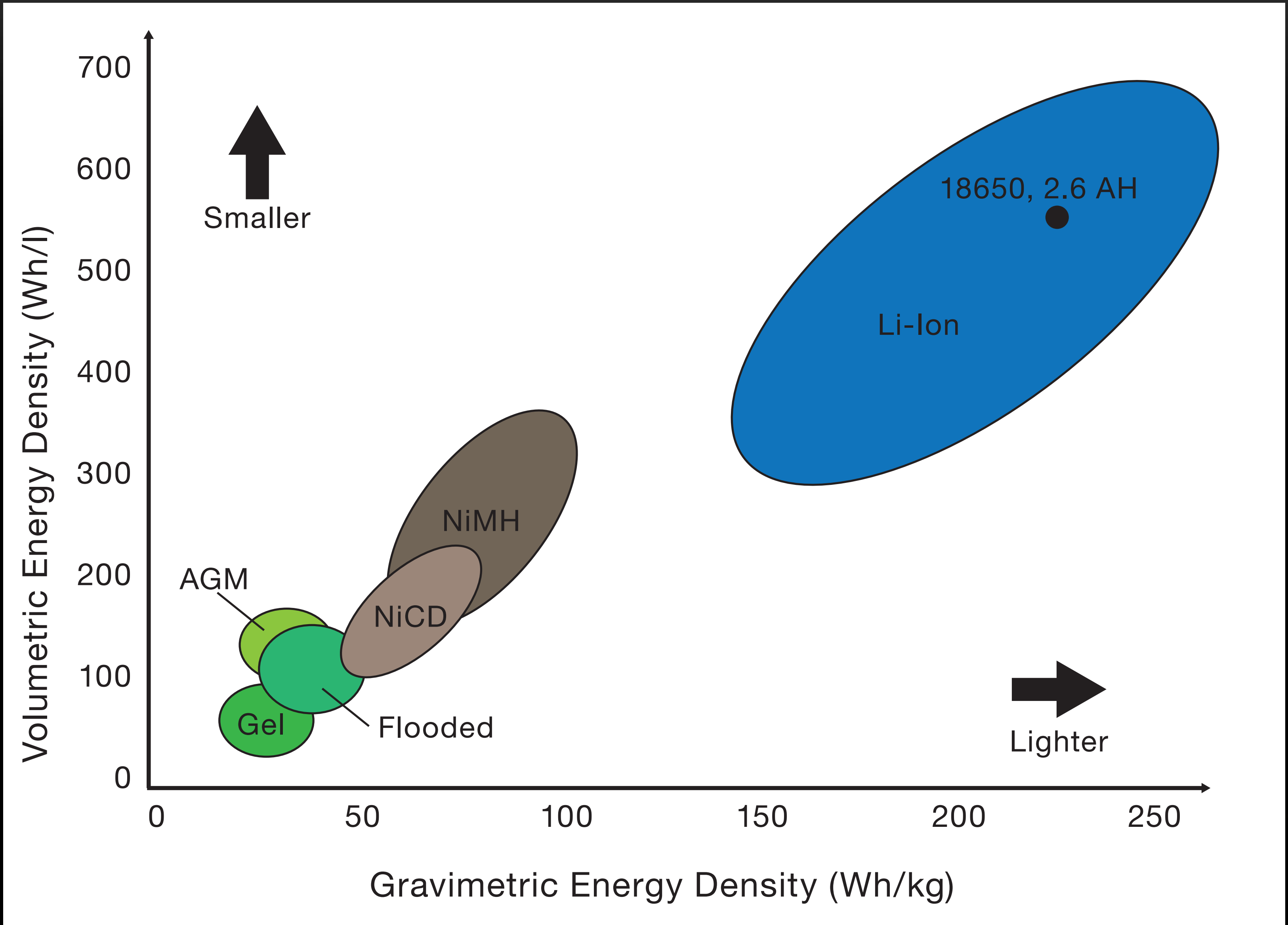
(Acumen Fund, 2012)

SUMMARY:
LITHIUM-ION ADVANTAGES OVER LEAD ACID

1. Energy density → 3x lighter & 2x smaller
2. Amp-hour efficiency → 100% versus 85%
3. Depth of Discharge → 100% versus 50%
4. Cycle life → 2-3x longer
5. High C-rate → 20x faster

Initial Cost of Battery ≠ the Levelized Cost of Storage (LCOS)

BATTERY ENERGY DENSITY



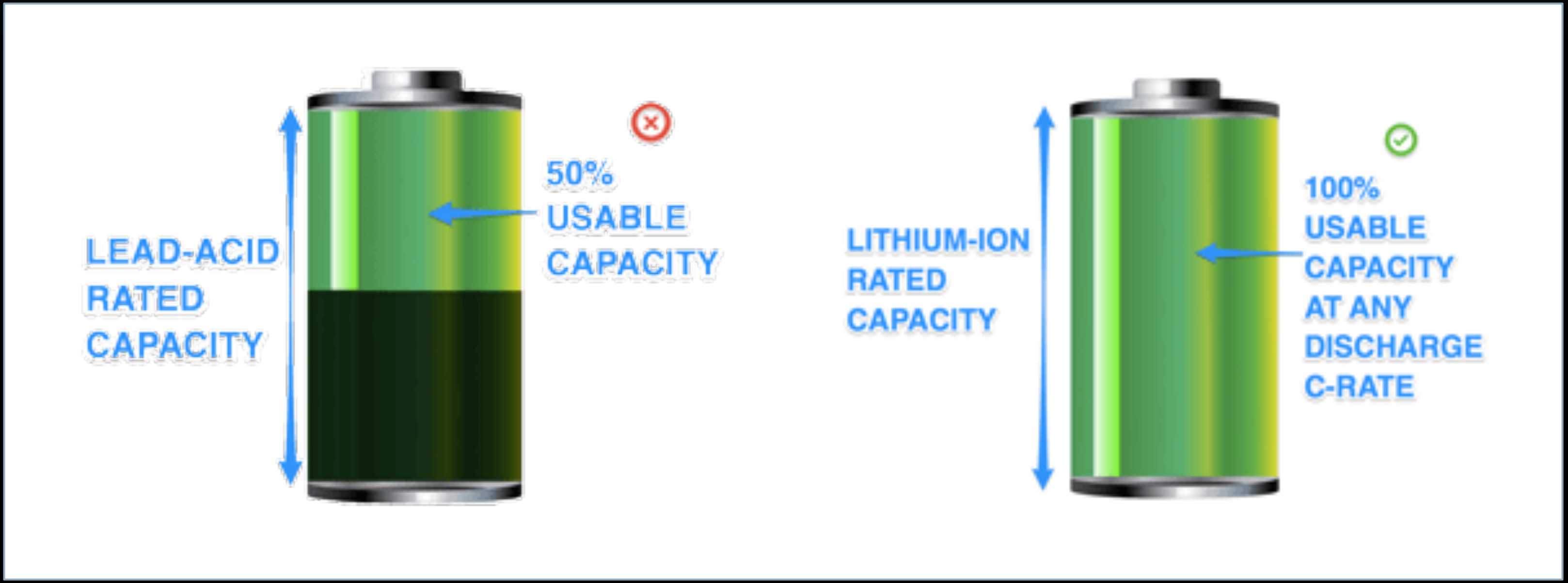
AMP-HOUR EFFICIENCY

- Charging Lithium-ion cells is 100% efficient*

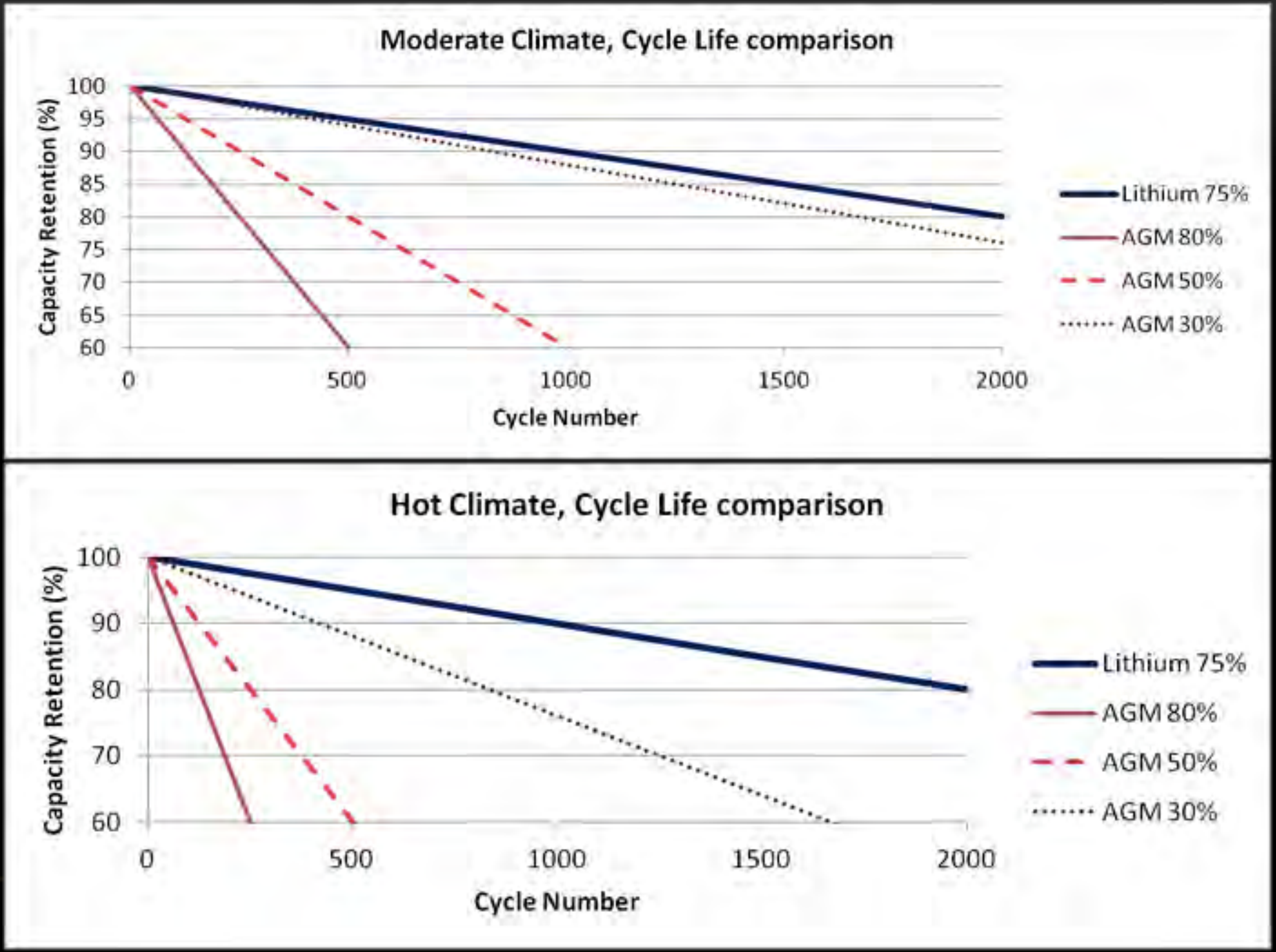
  *Practically, unless it sits long enough to experience self leakage

- Every electron that goes into a cell while charging from 0% to 100% SOC is available to come back out while discharging back down to 0% SOC, regardless of the rate of charge or discharge.
  - Note: The full <u>charge</u> can be recovered but not the <u>energy</u>, because the cell voltage is lower during discharge than during charge.

FULL DEPTH OF DISCHARGE



CYCLE LIFE



Notes:
2000 cycles ~ 5.5 years

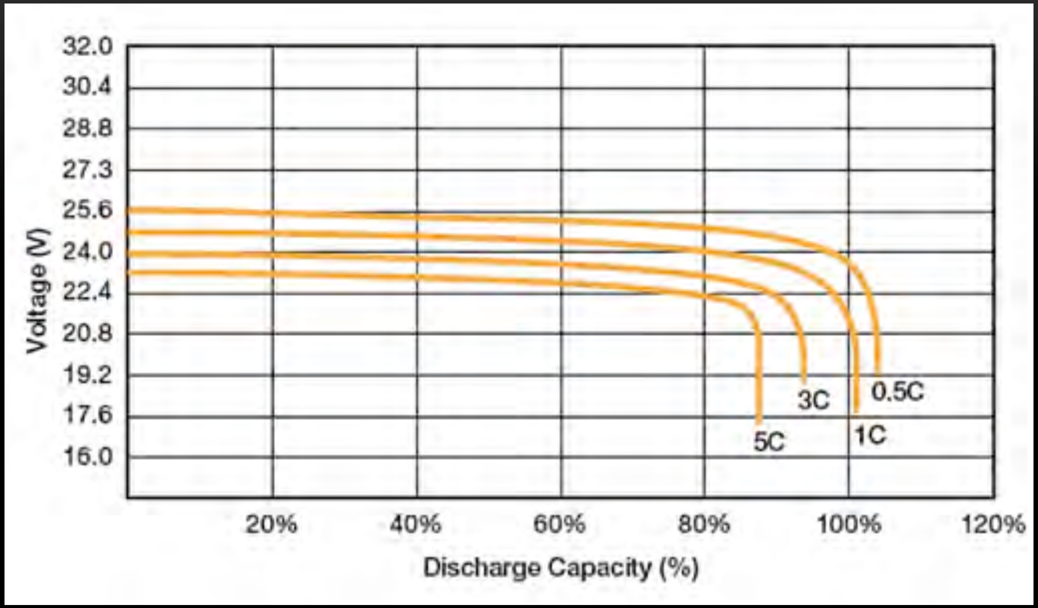
3000 cycles ~ 8 years

Source: https://www.altenergymag.com/content.php?post_type=1884

DISCHARGE CAPACITY VS TERMINAL VOLTAGE

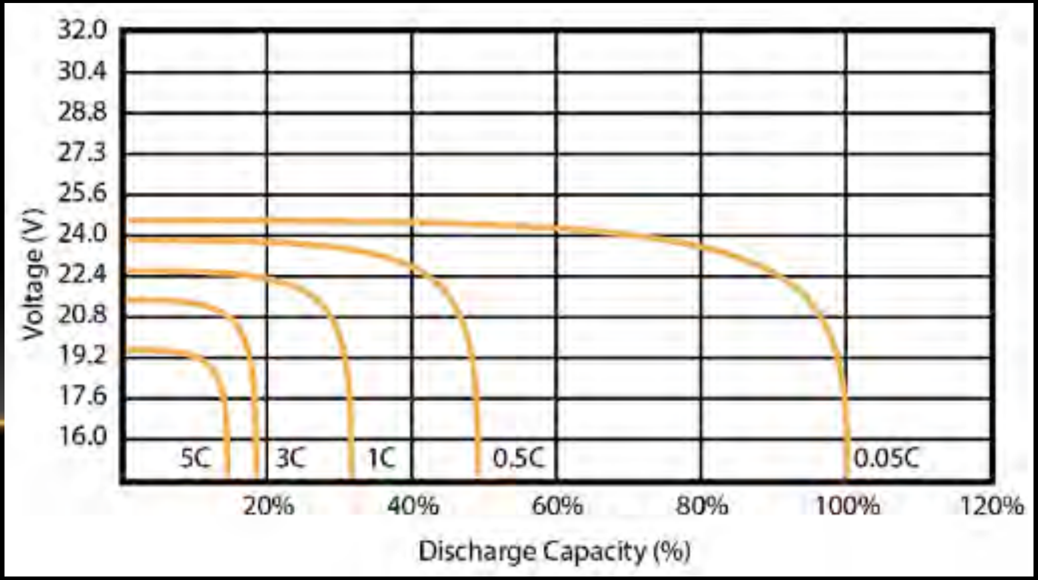
Lithium-ion

Holds capacity at high c-rate



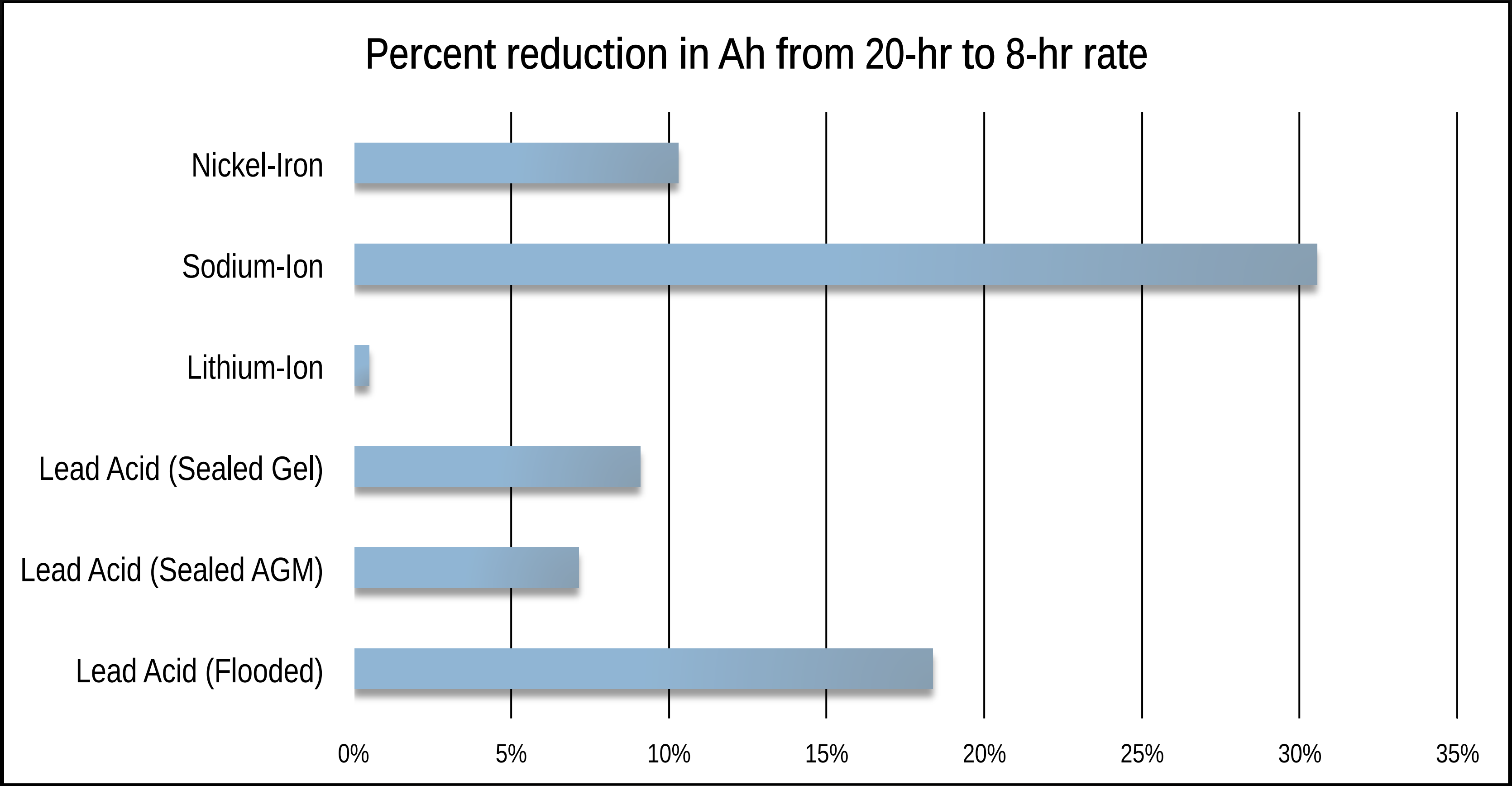
Lead Acid

Efficiency drops fast at high c-rate



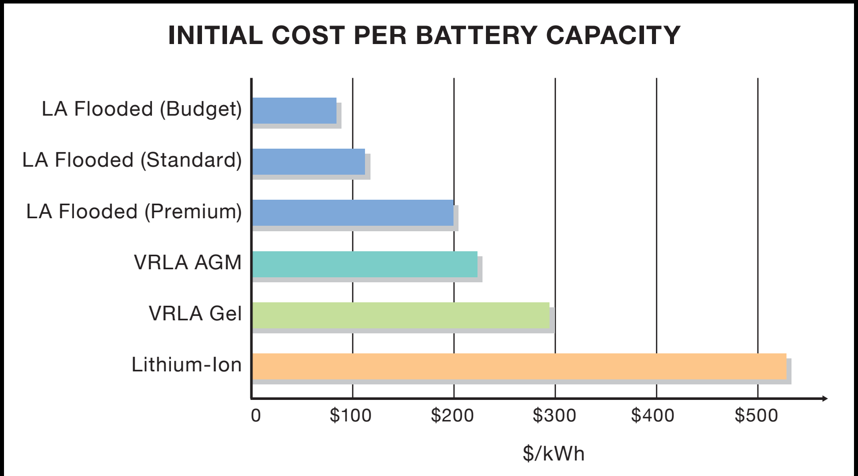
Source: https://www.victronenergy.com

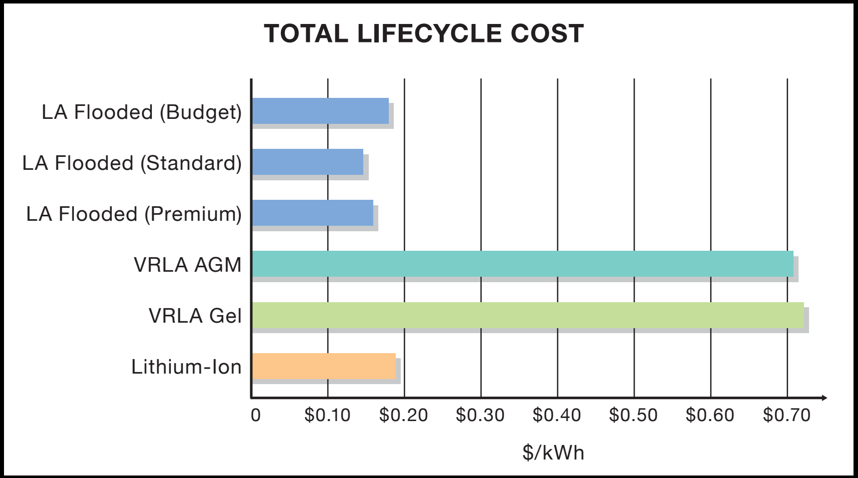
C-RATE EFFICIENCY



Based on datasheets of common readily available products

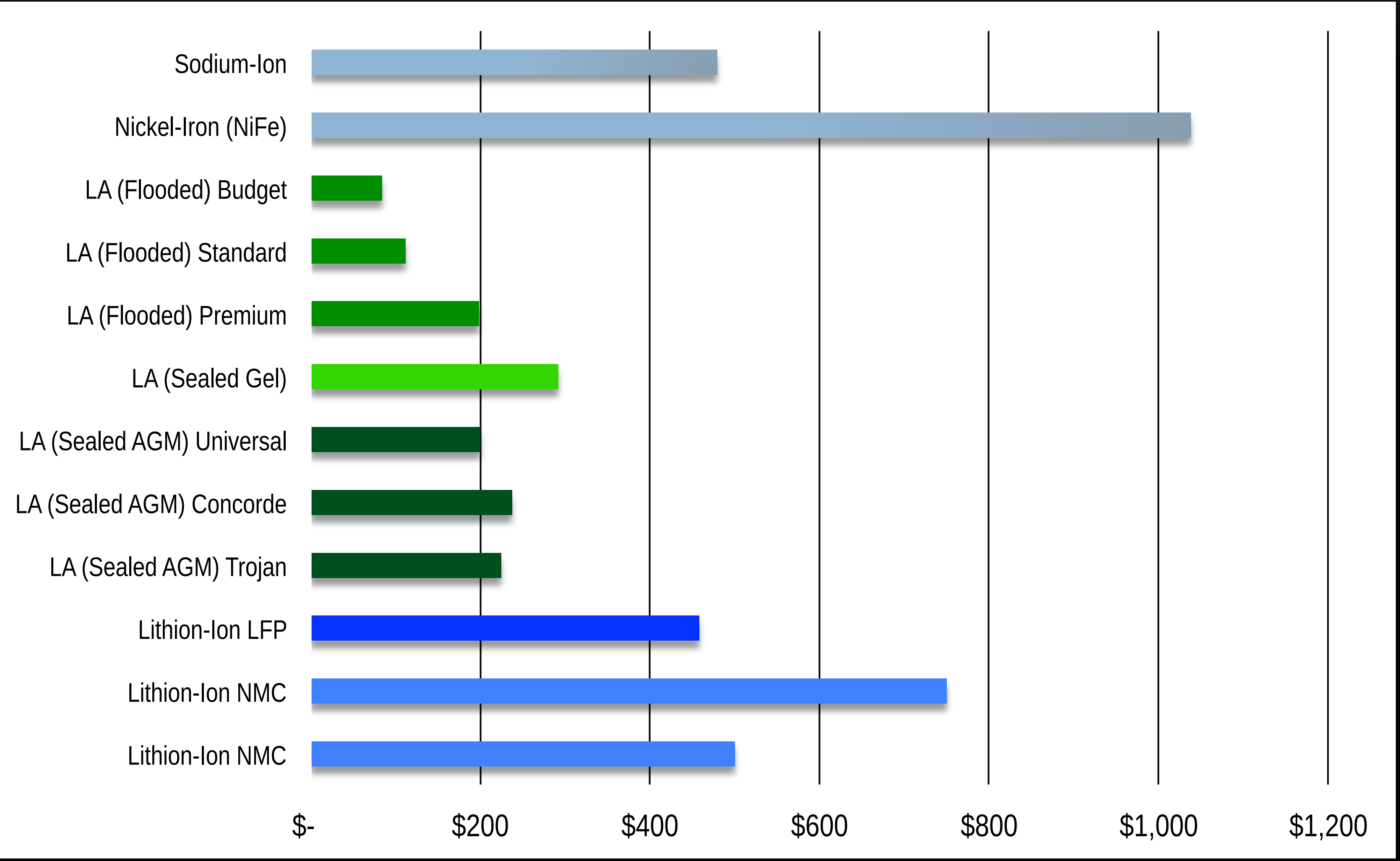
INITIAL COST VS LIFETIME COST





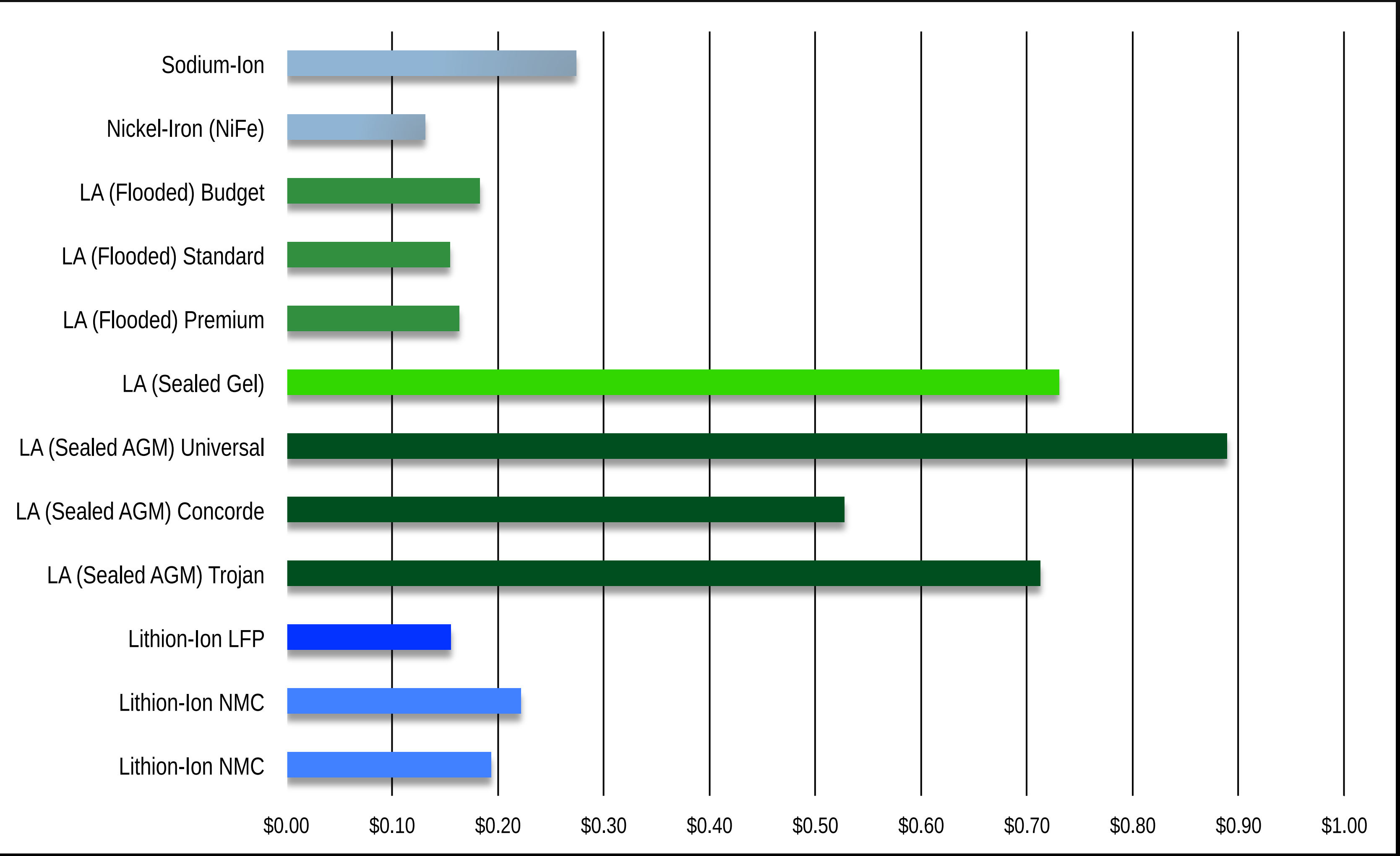
Graphs from my book: *Off Grid Solar*

INITIAL COST OF BATTERY ($/KWH)



Prices from online stores in August 2017

LIFETIME COST OF BATTERY



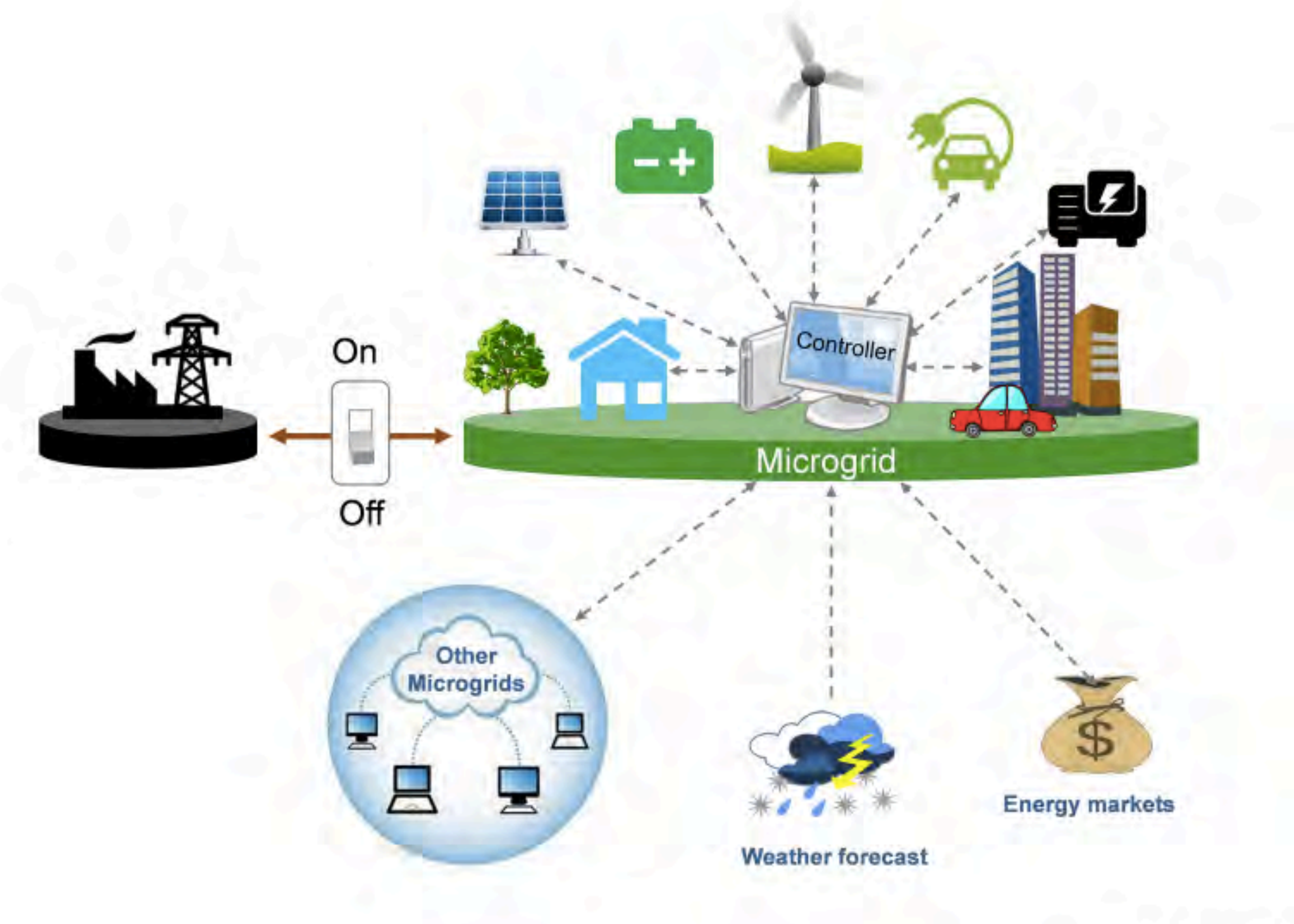
Prices from online stores in August 2017. Recommended DOD, cycle life, round-trip efficiency, 20-hr capacity from datasheet.

WHAT IS A MICRO GRID?

A small energy system capable of balancing captive supply and demand resources to maintain stable service within a defined boundary.

KEY CHARACTERISTICS OF A MICRO GRID:

- Connecting to the traditional grid is optional.
- Resiliency, reliability, and sustainability are the core responsibilities.
- Powering all system loads, not just the backup loads.
- Modern technology is needed to optimize energy production and usage.


Controller
On
Off
Microgrid
Other Microgrids
Weather forecast
Energy markets

VIRUNGA NATION PARK CASE STUDY

- GivePower Foundation
- Installed in July 2016 by SolarCity staff
- 45 kW of solar PV
- 45 kWh of energy storage
- Goal: change local energy economy

givepower

VIRUNGA NATIONAL PARK
Democratic Republic of the Congo

Bank of America

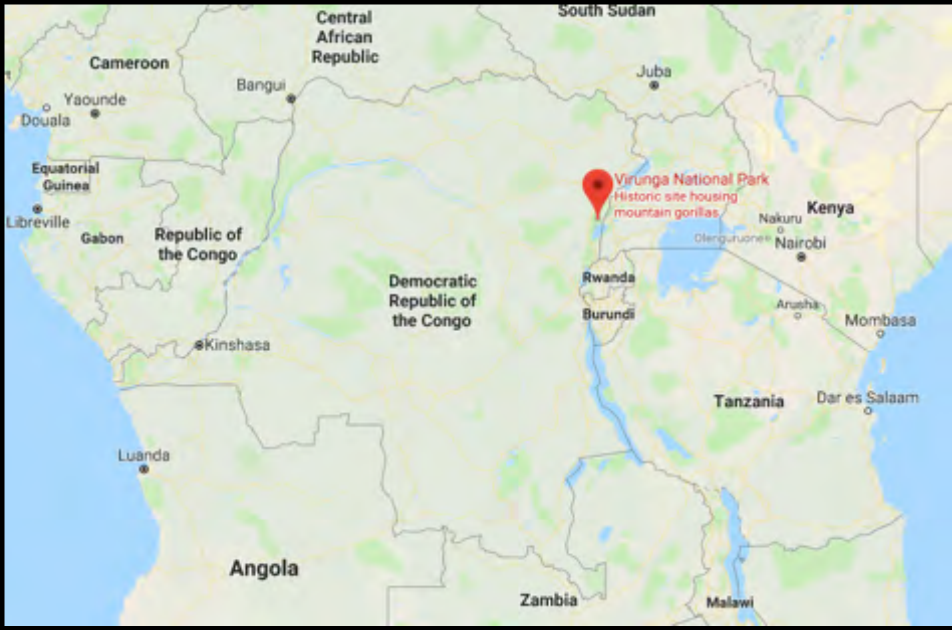
empoweredbylight.org

CanadianSolar

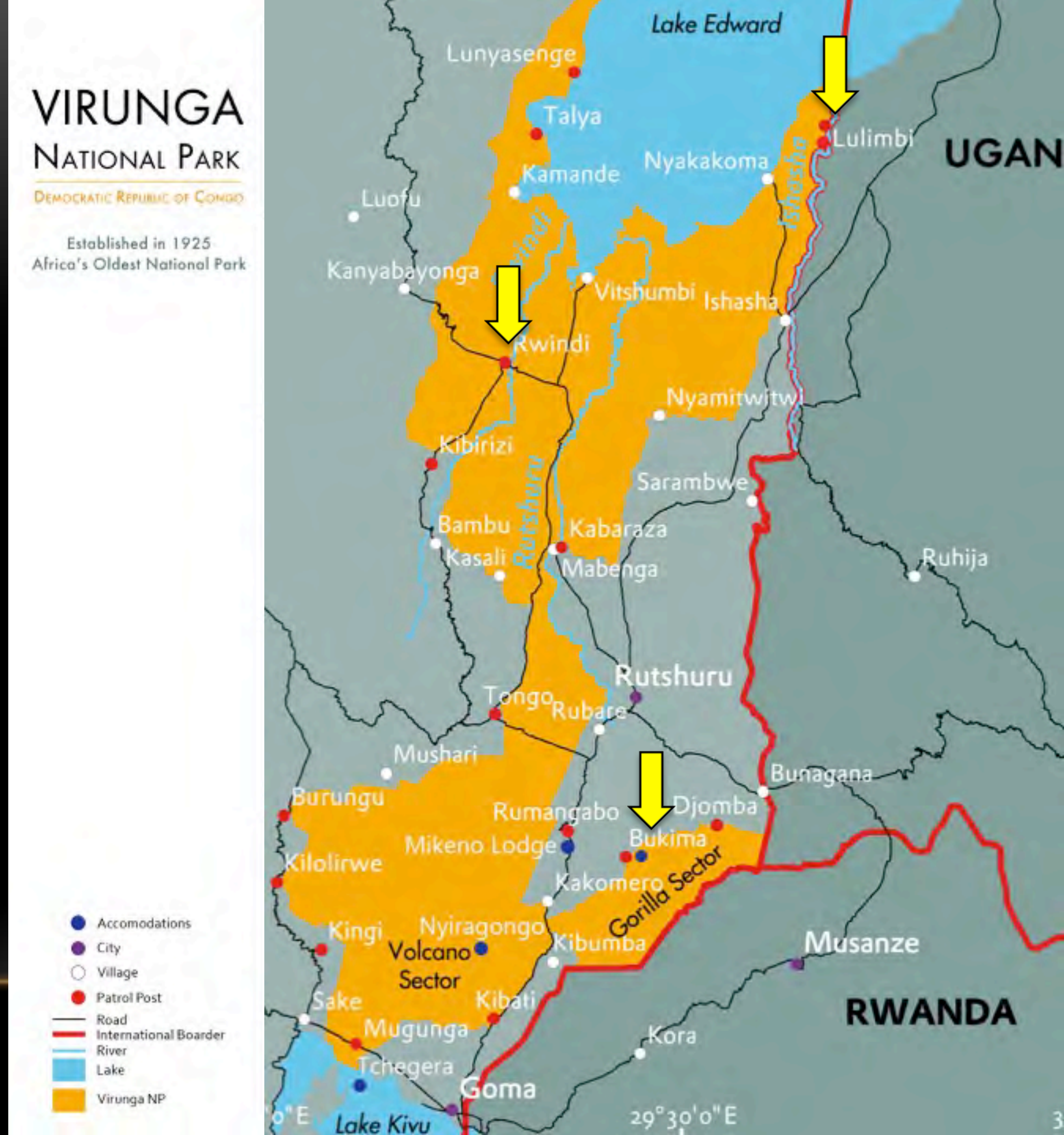
LEONARDO
DICAPRIO
FOUNDATION

https://player.vimeo.com/video/189078589

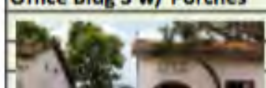
WHERE IS VIRUNGA NATIONAL PARK?

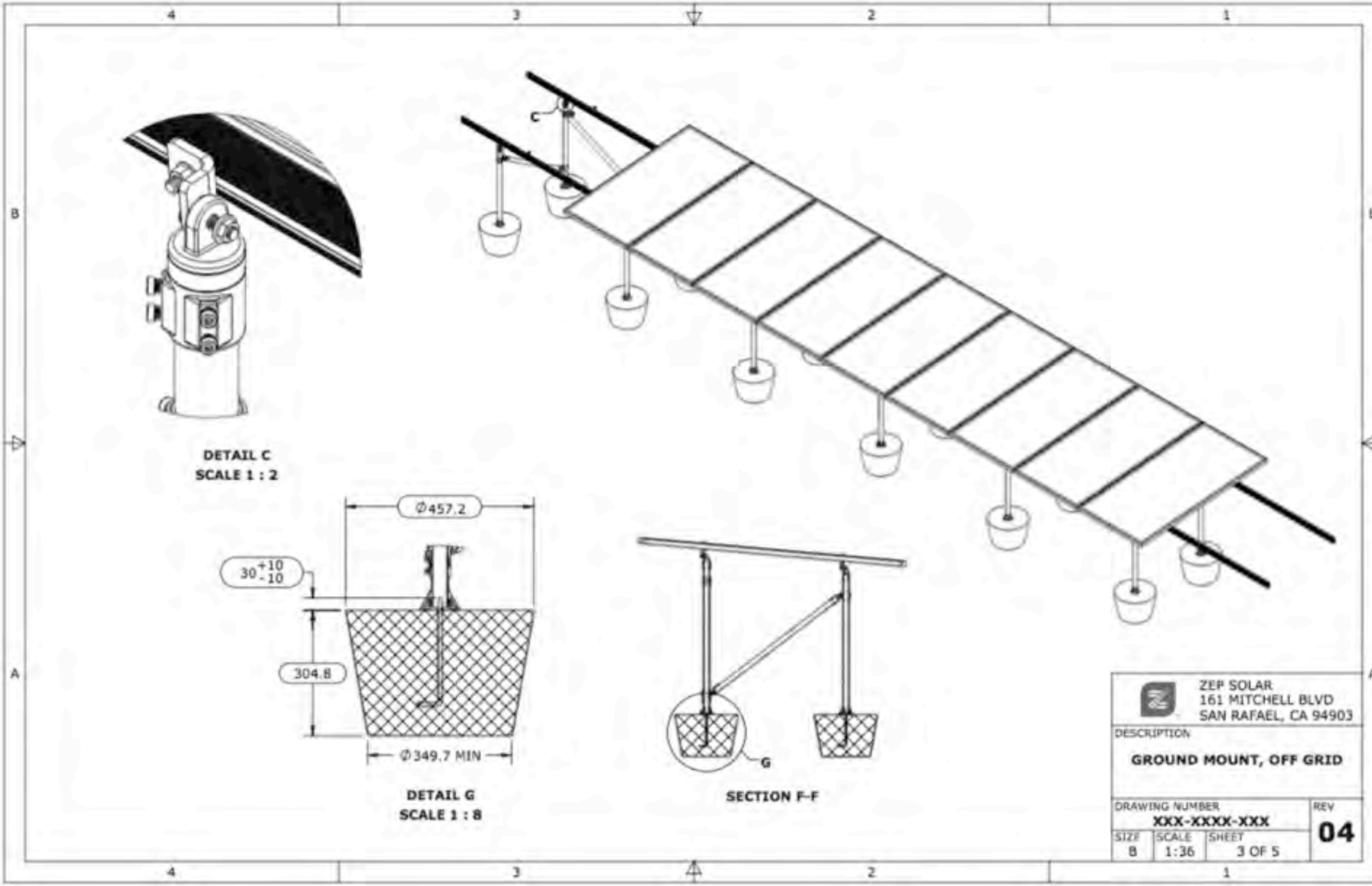



VIRUNGA
National Park
Democratic Republic of Congo
Established in 1925
Africa's Oldest National Park
Km
Beni
Rwenzori Mountains
Butembo
Kasese
Lubero
DR CONGO
Lake Edward
UGANDA
Bushenyi
Rutshuru
Kabale
Volcano Sector
Gorilla Sector
Musanze
RWANDA
Goma
Lake Kivu
Accomodations
City
Village
Patrol Post
Road
International Boarder
River
Lake
Virunga NP


VIRUNGA
National Park
Democratic Republic of Congo
Established in 1925
Africa's Oldest National Park
Accomodations
City
Village
Patrol Post
Road
International Boarder
River
Lake
Virunga NP
Lake Edward
Lunyasenge
Talya
Kamande
Nyakakoma
Lulimbi
UGAN
Luofu
Kanyabayonga
Vitshumbi
Ishasha
Rwindi
Nyamitwitwi
Kibirizi
Sarambwe
Bambu
Kasali
Rutshuru
Kabaraza
Mabenga
Ruhija
Tongo
Rubare
Mushari
Burungu
Rumangabo
Djomba
Bunagana
Mikeno Lodge
Bukima
Kilolirwe
Kakomero
Gorilla Sector
Kingi
Nyiragongo
Volcano
Sector
Kibumba
Musanze
Sake
Kibati
RWANDA
Mugunga
Kora
Tchegera
Goma
Lake Kivu
29°30'0"E

	PV	PV	PV Output	Inverter Output		
	Qty	Watts	kW	kW	kWh/kW	kWh/day
PV Daytime Power & Energy	22	310	6.82		1800	33.63
Inverter Power & Energy				5.0	1800	24.66

Location	Appliance	Qty	Running Wattage (W)	Surge Wattage (W)	Running Wattage Subtotal (W)	AVG Daily Usage (hours)	Total Energy Watt-hours (Wh)	Essential?
Main Office Bldg								
	Office LED bulbs	16	8		128	6	768	Y
	Laptops	10	100		1,000	8	8,000	Y
	Printers	2	40		80	8	640	Y
	Flat Screen TV	1	200		200	6	1,200	Y
	Refrigerator (small)	2	500	1,200	2,400	24	57,600	Y
	Other plug loads	4	10		40	24	960	Y
	Bathroom LED bulbs (1 per)	2	8		16	1	16	Y
Peak Power					3,864			
Daily Energy Consumption							69,184	
Office Bldg 1 w/ Porches								
	Office LED bulbs	2	8		16	6	96	N
	Radio chargers	12	50		600	6	3,600	Y
	GPS units	12	50		600	6	3,600	Y
	Laptops	10	100		1,000	8	8,000	N
	Printer	1	40		40	8	320	N
	Satellite communication	1	300		300	24	7,200	Y
	Resistance Cookers	4	1,000	1,000	4,000	5	20,000	N
Peak Power					6,556			
Daily Energy Consumption							42,816	
Office Bldg 2 w/ Porches								
	Office LED bulbs	2	8		16	6	96	N
	Radio chargers	12	50		600	6	3,600	Y
	GPS units	12	50		600	6	3,600	Y
	Laptops	10	100		1,000	8	8,000	N
	Printer	1	40		40	8	320	N
	Satellite communication	1	300		300	24	7,200	Y
Peak Power					2,556			
Daily Energy Consumption							22,816	
Office Bldg 3 w/ Porches								
	Office LED bulbs	2	8		16	6	96	N
	Radio chargers	12	50		600	6	3,600	Y
	GPS units	12	50		600	6	3,600	Y



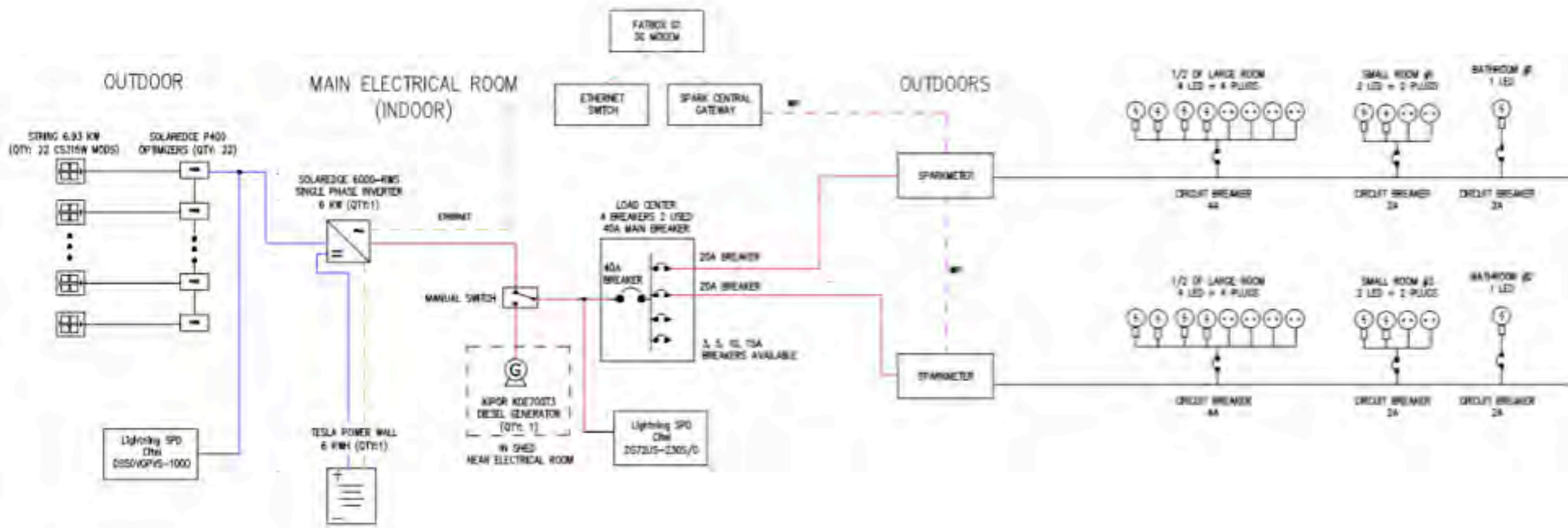
C
DETAIL C
SCALE 1 : 2
Ø457.2
30 +10 -10
304.8
Ø349.7 MIN
DETAIL G
SCALE 1 : 8
G
SECTION F-F
ZEP SOLAR
161 MITCHELL BLVD
SAN RAFAEL, CA 94903
DESCRIPTION
GROUND MOUNT, OFF GRID
DRAWING NUMBER
XXX-XXXX-XXX
REV
04
SIZE
B
SCALE
1:36
SHEET
3 OF 5


N

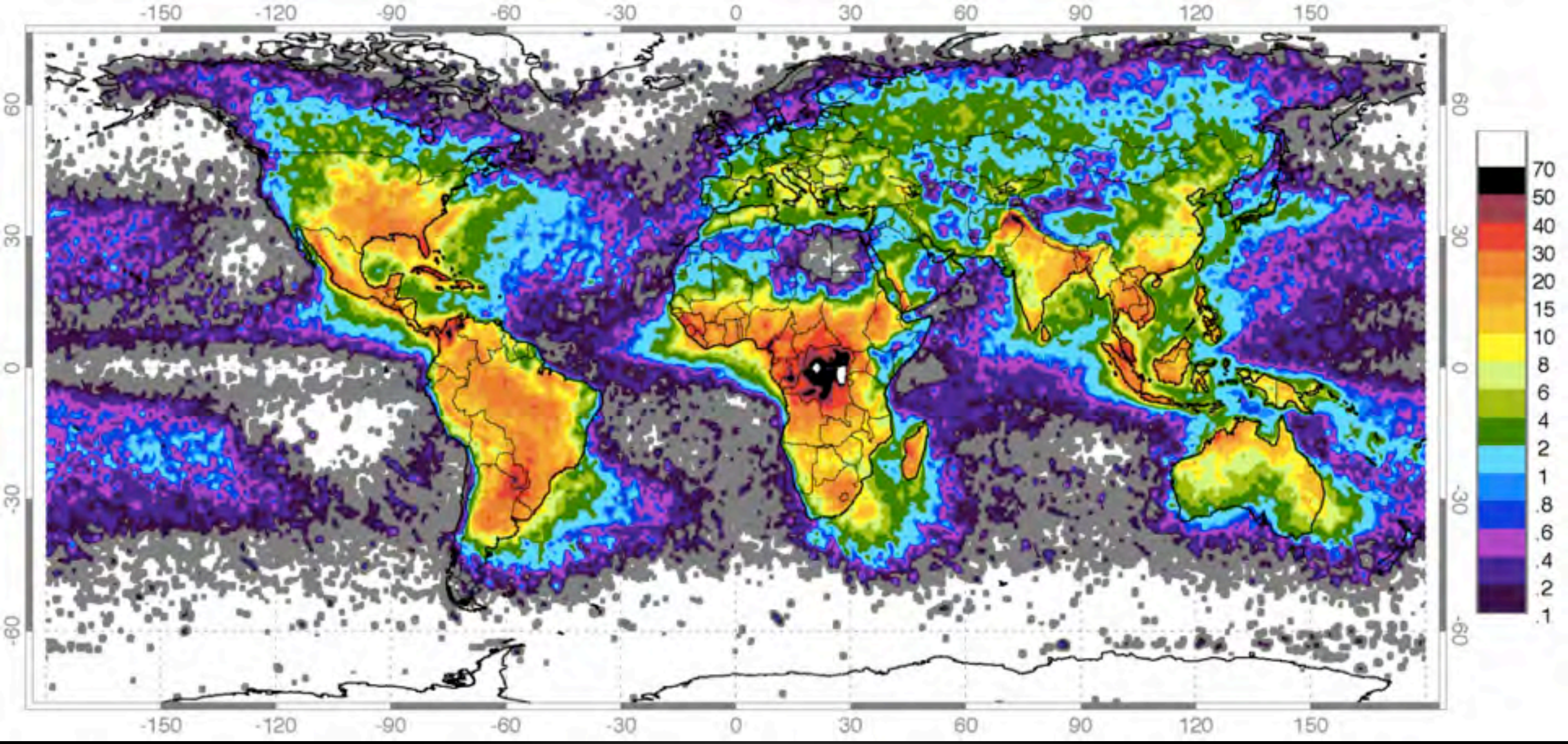
SINGLE LINE DIAGRAM

RWINDI NANO GRID

MAIN BUILDING CIRCUIT – WITH GENERATOR



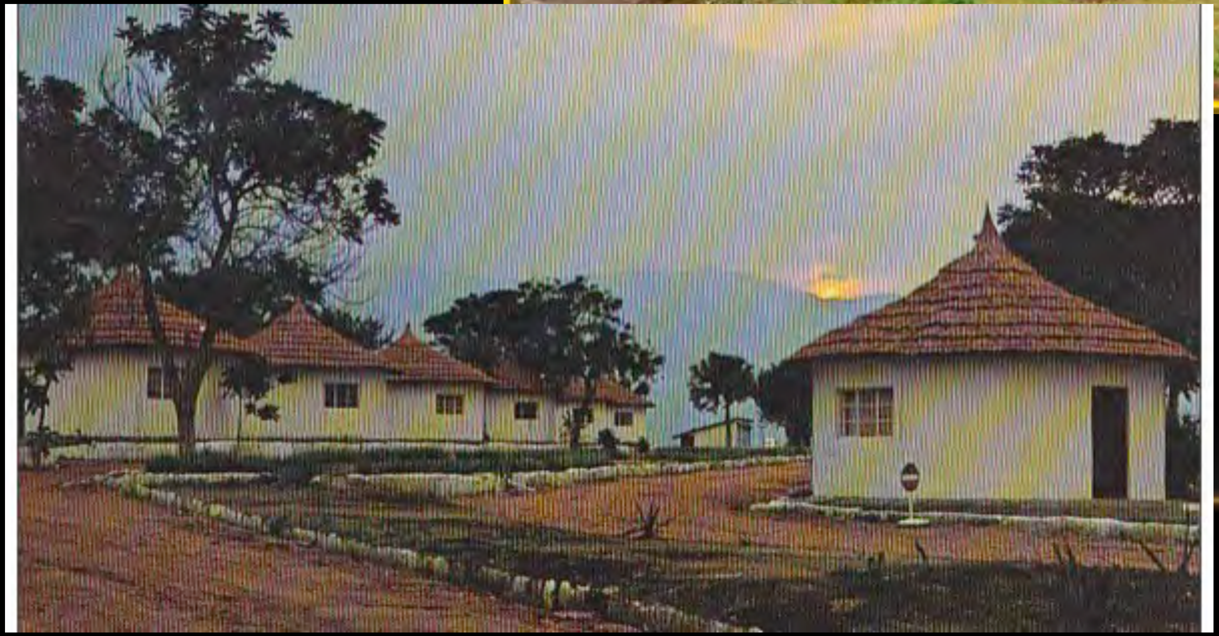
GLOBAL LIGHTNING FREQUENCY



Data from space-based sensors reveal the uneven distribution of worldwide lightning strikes. Units: flashes/km2/yr.
Data obtained from April 1995 to February 2003 from NASA's Optical Transient Detector and from January 1998 to February 2003 from NASA's Lightning Imaging Sensor.


FUSO

RWINDI

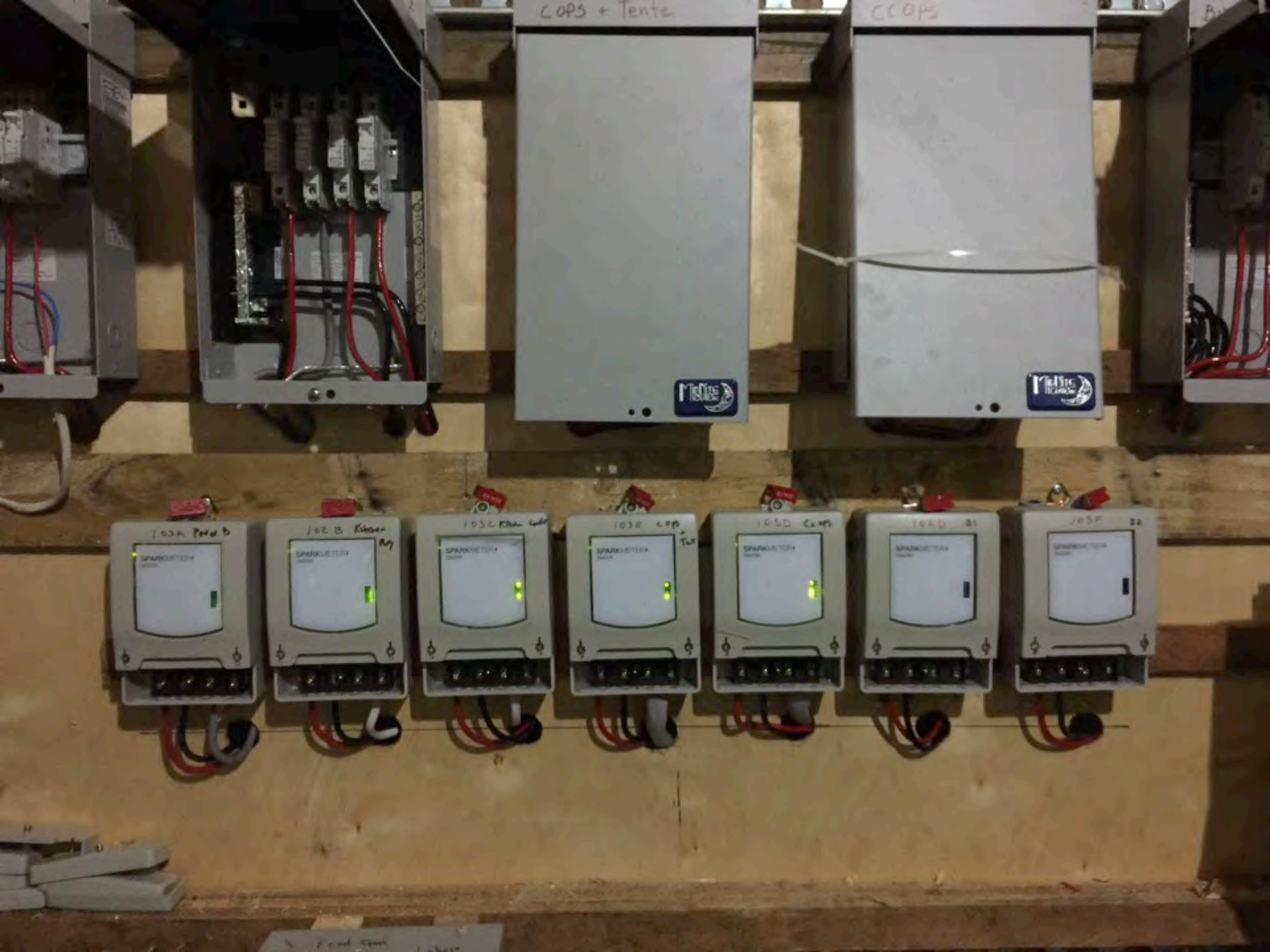



ROMO
9


TESLA


TESLA


ON
OFF
ON


COPS + Tente
CCOPS


LULIMBI

BUKIMA


TESLA

Great Success!

THANK YOU!

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