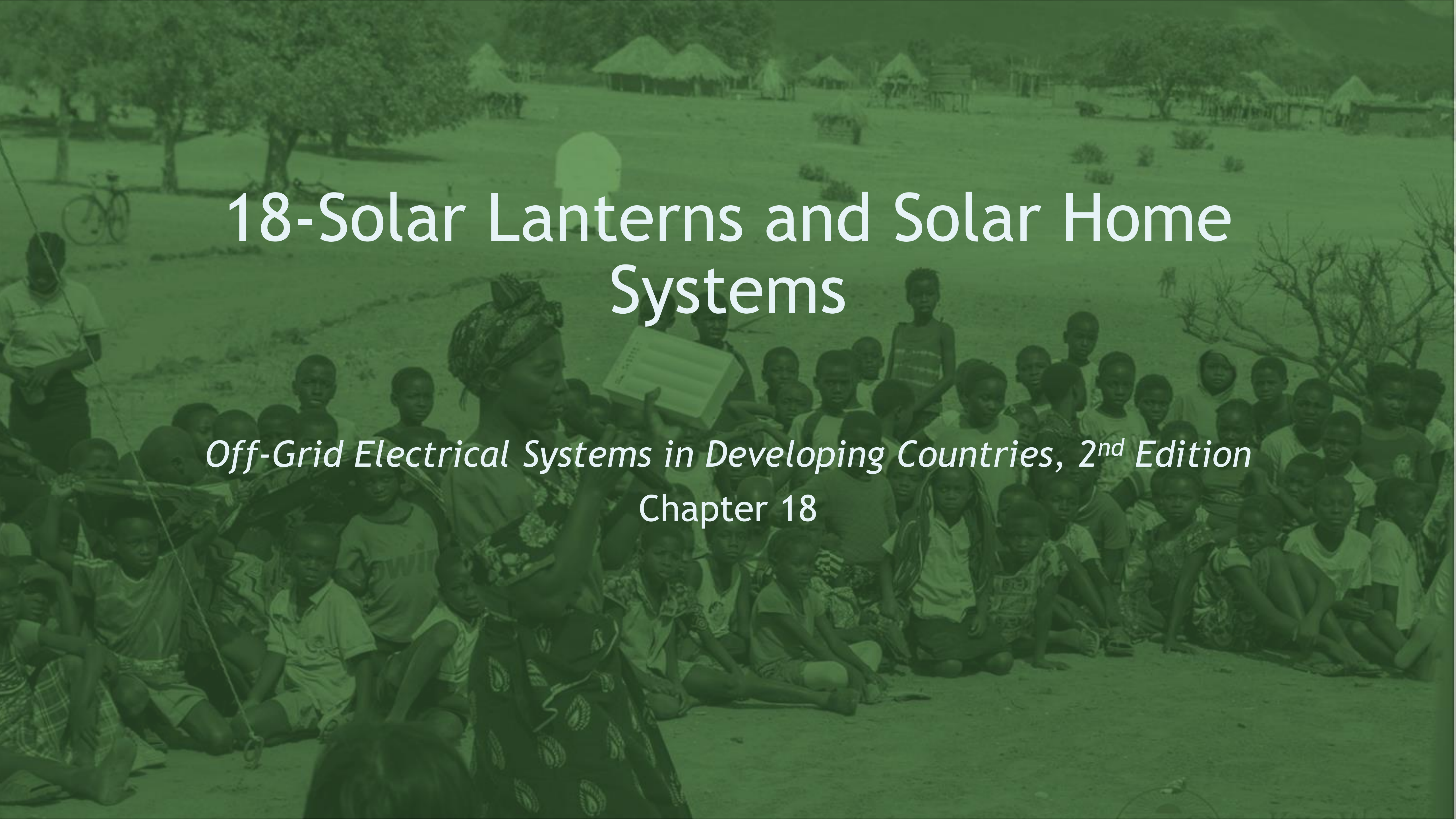


18-Solar Lanterns and Solar Home Systems

Off-Grid Electrical Systems in Developing Countries, 2nd Edition

Chapter 18

Preface

- These lectures slides are intended to accompany the textbook *Off-Grid Electrical Systems in Developing Countries*, *2nd Edition, 2025* written by Dr. Henry Louie and published by SpringerNature
- Additional content, explanations, derivations, examples, problems, errata, and other materials are found in the book and on www.drhenrylouie.com
- To request solutions, explanations, permissions to use author-supplied images, or if you notice an error, please email the author at hlouie@ieee.org
- Inquiries about guest lectures, seminars, or trainings can be made to hlouie@ieee.org
- If you want to support work in electricity access, consider donating to KiloWatts for Humanity or IEEE Smart Village

Learning Outcomes

At the end of this lecture, you will be able to:

✓Describe the use of solar lanterns and solar home systems in off-grid electrification, emphasizing the key technical, economic, environmental, and social considerations

✓Perform engineering calculations relevant to the design and operation of solar lanterns and solar home systems

✓Compare and contrast the common business models used with solar lanterns and solar home systems

Introduction

- Solar Lanterns (SL) and Solar Home Systems (SHS) provide lower-tier electricity access than other electrification approaches
  - modest access is still meaningful
  - less expensive electrification approach than mini-grids, etc.
- +50 million units sold in 2024
- Least-cost solution for approx. 40% of people without grid connection

(*courtesy BBOXX*)

(*courtesy d.light*)

Solar Lanterns ("pico solar")

- "Entry level" electricity access
- Components
  - PV panel (<10 W)
  - battery (usually <20 Wh)
  - LED light(s)
  - USB port for charging (on larger systems)
- Designed for portability
- Low-cost US$5-US$20

d.Light S30

source: dlight.com

Sun King Pro 2000

source: sunking.com

M-KOPA 4

source: m-kopa.com

Solar Home Systems (SHS)

- Higher-tier electricity access
- Components
  - larger PV panel (usually 20W to 60W)
  - battery (100Wh-300Wh)
  - LED lights
  - USB ports
  - inverter (larger systems)
  - appliances (DC TVs, fans)

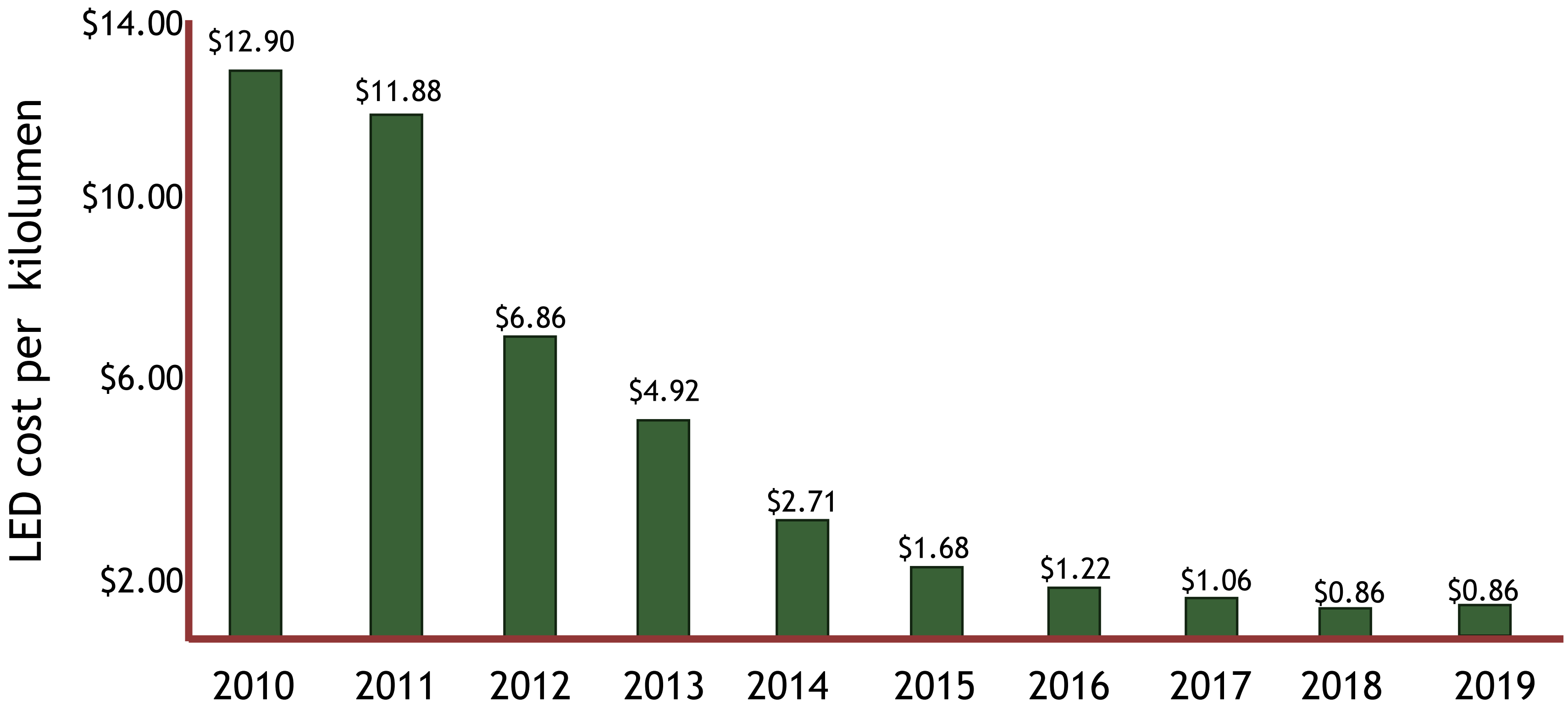
BBOXX
(*courtesy BBOXX*)

d.light X850
source: dlight.com

Drivers for SL/SHS Adoption

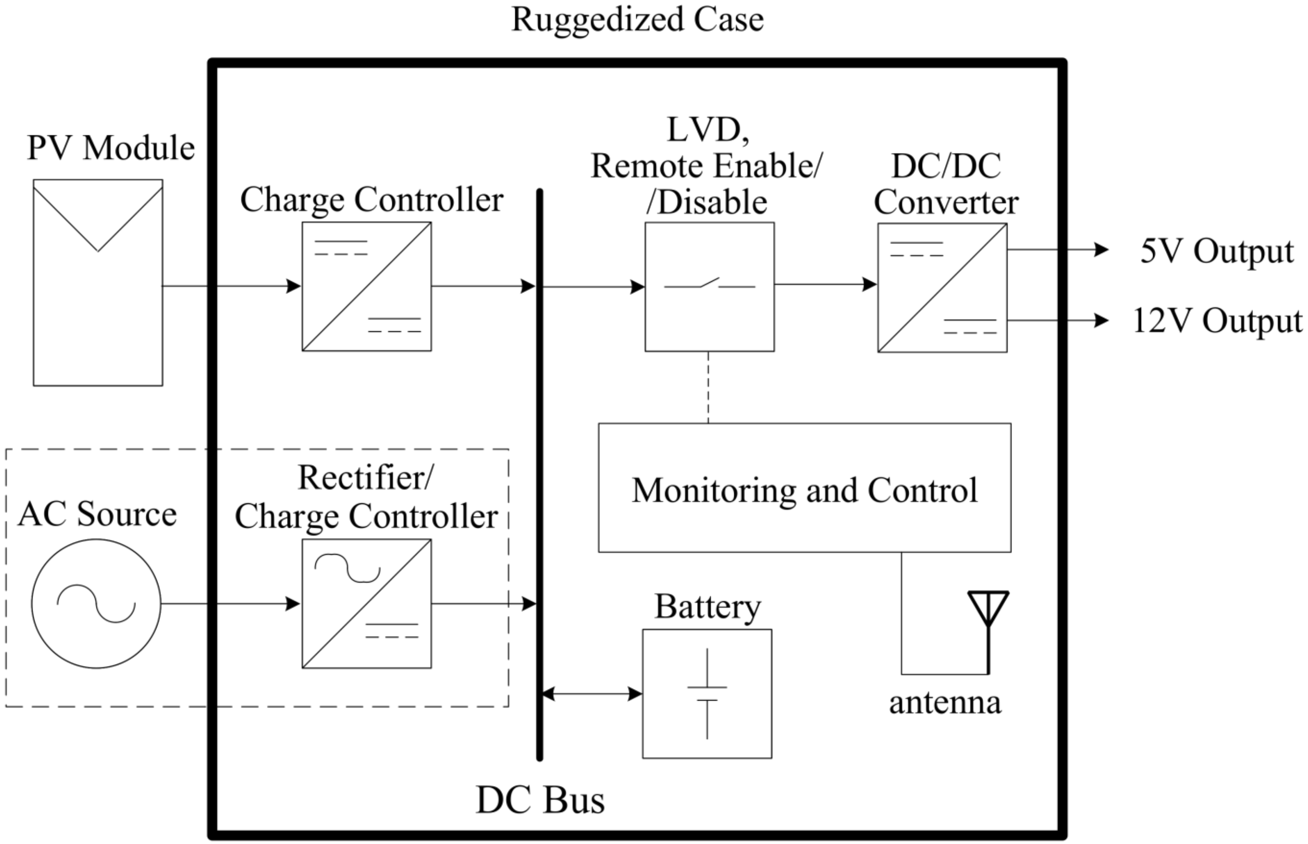
- Decreasing PV, battery, and LED costs
  - LED costs decreased by 50% from 2009 to 2015
- High cost, low desirability of alternative illumination methods
  - kerosene
  - candles
- High penetration of mobile phones
  - 92 mobile phone subscription for every 100 people in SSA
- Increased network coverage makes pay-as-you-go and other business models viable

LEDs are less expensive, more widely available, and more energy-efficient



Source: U.S. Department of Energy

SHS Design Components

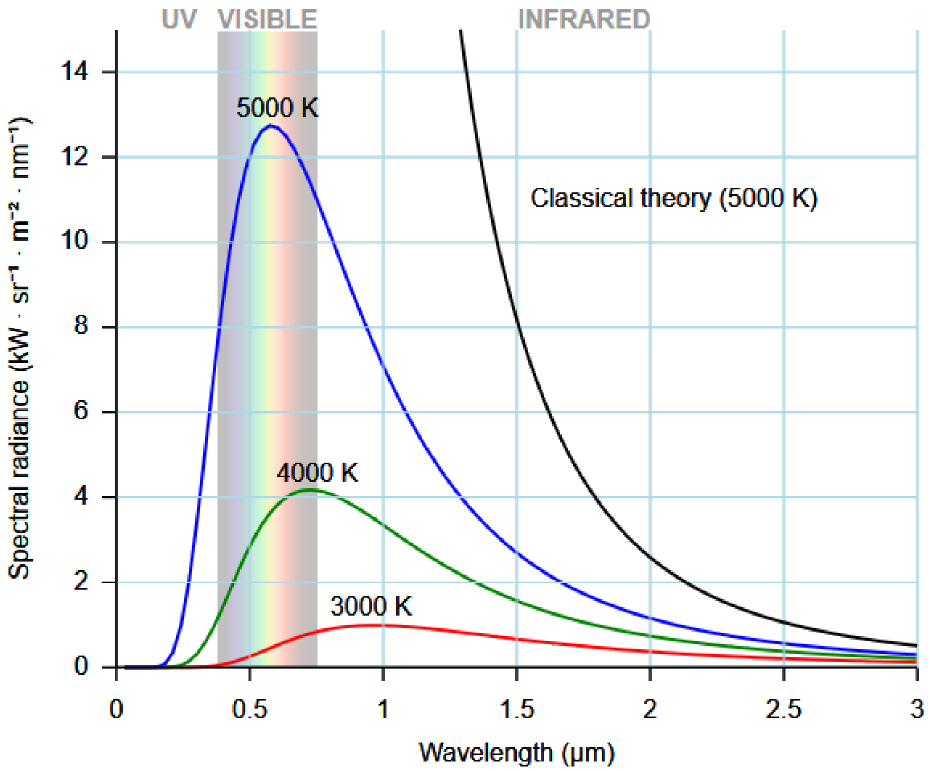


Illumination Concepts

- Primary value proposition of SL is that they are less expensive than kerosene and produce higher-quality light
- Estimates that over US$3 is saved for ever US$1 spent on pico solar
- How do you compare one light source against another?

Electromagnetic Radiation

blackbody radiation



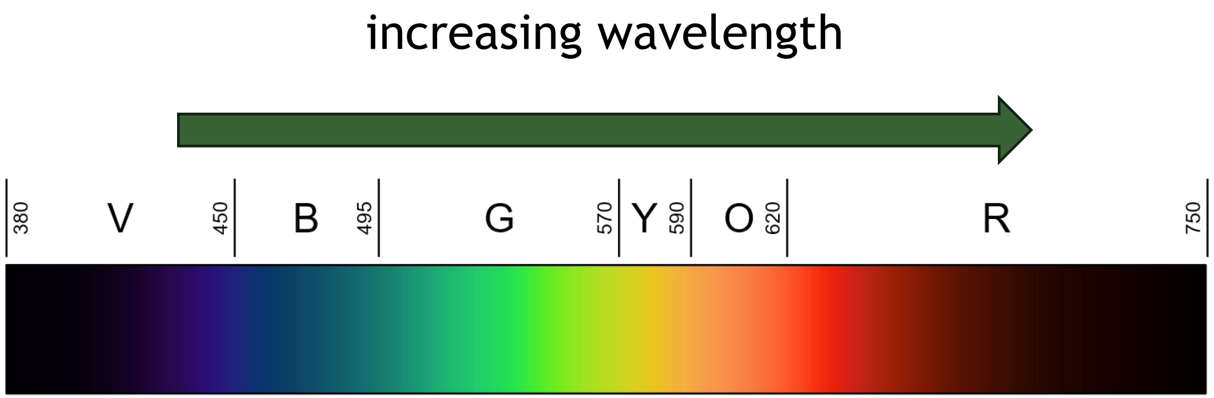
power is distributed across a range of wavelengths, but we are only interested in the those in the visible range

"Black body" by Darth Kule - Own work. Licensed under Public Domain via Commons - https://commons.wikimedia.org/wiki/File:Black_body.svg#/media/File:Black_body.svg

Light

Light is electromagnetic radiation of varying wavelengths that are visible to the human eye

- Approx 400-700 nm wavelengths

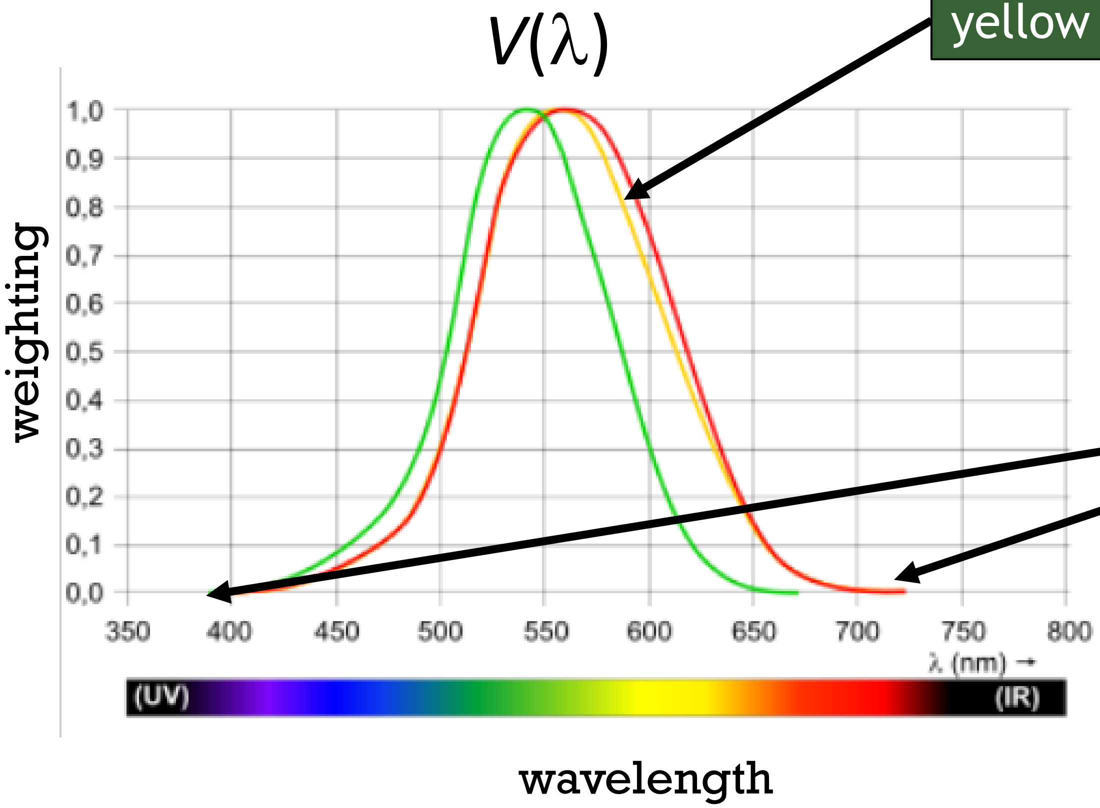


By Gringer - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=4639774

Luminosity Function

- Need to distinguish power and energy in the visible spectrum from power and energy in the entire spectrum
- Human eyes have different sensitivities to different wavelengths in the visible spectrum
  - most sensitive: ~550 nm (yellow-green)
- Power of light is found by the weighted sum of the power associated with each frequency
- Weighting accounts for human vision sensitivity and is determined by the "luminosity function" $V(\lambda)$

Luminosity Function

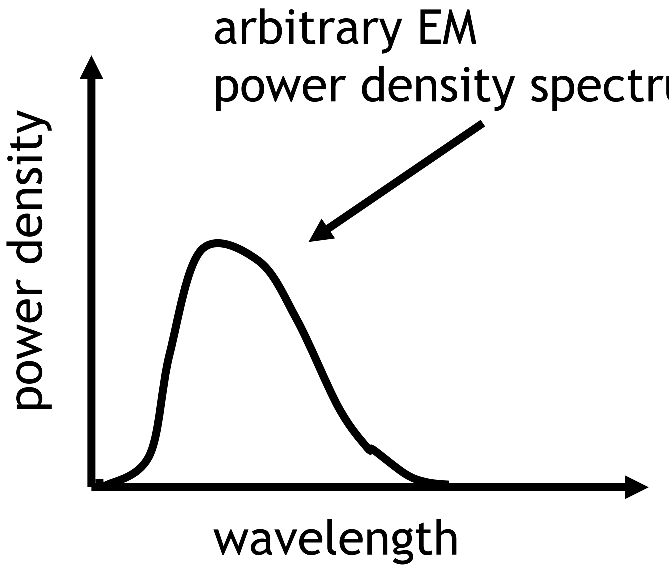


yellow (photopic) curve is commonly used

wavelengths outside the visible spectrum wave a weighting of 0

"LuminosityCurve2" by Raoul NK - Own work. Licensed under CC BY-SA 3.0 via Commons - https://commons.wikimedia.org/wiki/File:LuminosityCurve2.svg#/media/File:LuminosityCurve2.svg

Luminosity Function



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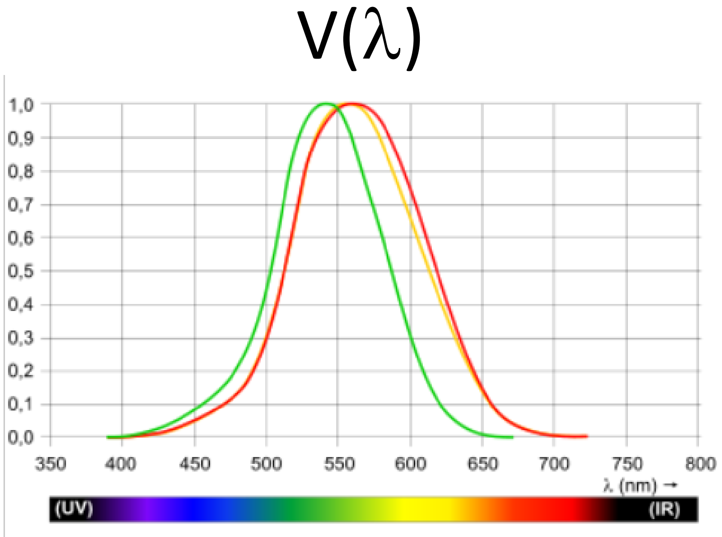

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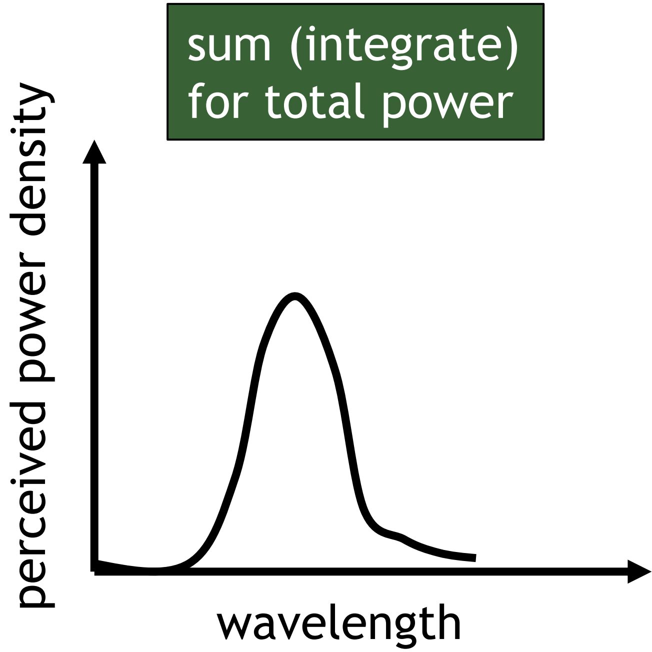


multiply the power density at each wavelength by the weighting function evaluated at that wavelength

Luminous Flux (*F*)

Visible (perceived) power in a spectrum of electromagnetic radiation is called “luminous flux”

- units: lumens (lm)
- measures luminous energy/time (power of visible electromagnetic radiation)

Luminous Efficacy (η_L)

- Measurement of how well a lamp converts input power to perceived power (luminous flux)

$$\eta_L = \frac{F}{P_{lamp}}$$

η_L : luminous efficacy (lm/W)
P_{lamp}: input power

- Maximum value is 683 lm/W
- "Efficiency" is not used, as we do not care about power output to the EM spectrum not visible to the human eye

Typical Lumen Output

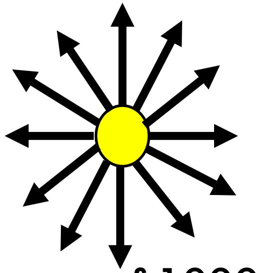
Technology	Lumens
White LED (1 W)	25-120
Kerosene Lamp	10-100
Incandescent Bulb (40 W)	325
White LED (7 W)	450
Florescent Bulb (18 W)	1250
Incandescent Bulb (100 W)	1750

LED bulbs have the highest efficacy, incandescent bulbs are lower, and kerosene lamps are extremely low

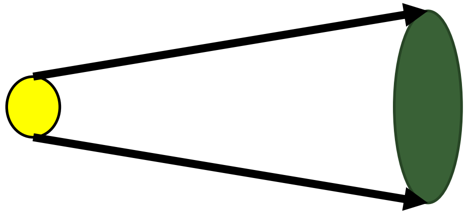
Luminous Flux

- Luminous flux (lumens) describes the visible power from a light source
- Lumen value alone is not enough to characterize a light source
- Consider the difference between a torch and a florescent light tube
  - a torch (flashlight) concentrates (focuses) the light on a smaller area—it appears brighter within that area

Candela



Point source of 1000 lumens
emitting light in all directions
(three dimensional)



Source of 1000 lumens
emitting light in a focused pattern.

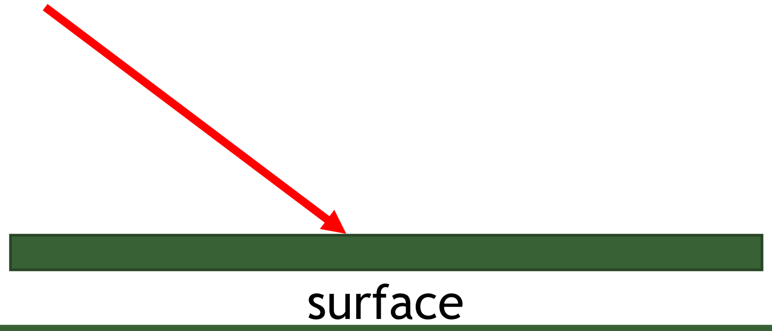
which is perceived to be brighter?

Candela (I_V)

- Luminous intensity is known as the “candela”
- Accounts for how the lumens are emitted from the light source
- Luminous flux (power) per unit solid angle as emitted by a light source
- A common candle emits approximately one candela of luminous intensity

Illuminance (E_V)

- Amount of light incident to a surface (e.g. a desktop, roadway, floor, artwork)
- Surface properties do not affect the illuminance
- Independent of the observer
- Unit: Lux (lumen/m^2)



Typical Indoor Lux Values

Condition	Lux (lm/m^2)
Public areas with dark surroundings	20 - 50
Simple orientation for short visits	50 - 100
Working areas where visual tasks are only occasionally performed	100 - 150
Warehouses, Homes, Theaters, Archives	150
Easy Office Work, Classes	250
Normal Office Work, PC Work, Study Library, Groceries, Show Rooms, Laboratories	500
Supermarkets, Mechanical Workshops, Office Landscapes	750
Normal Drawing Work, Detailed Mechanical Workshops, Operation Theaters	1,000
Detailed Drawing Work, Very Detailed Mechanical Works	1500 - 2000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2000 - 5000
Performance of very prolonged and exacting visual tasks	5000 - 10000
Performance of very special visual tasks of extremely low contrast and small size	10000 - 20000

Most SL, SHS provide lux at a lower level. However, the light they do provide is meaningful, safer, and less expensive than most alternatives

Standards

- Markets are flooded with generic (“off-brand”) SLs and SHS
- Form factor and even logos appear to be name brand, but the quality is inferior (batteries, LEDs, PV panels maybe low quality)
- Creates confusion, customer reluctance to buy
- Global Off-Grid Lighting Association (gogla.org) provides ratings of different products

Solar Lantern Performance

Solar lanterns are often rated based on

- run time (on full battery)
- run time (per day of solar charging)
- total light output (lumens)
- area with >50 Lux (m^2)
- total lighting service (lumen-hours/solar day)

Example—d.light S20

- PV rating: 0.4 W
- Battery rating: 400 mAh (Lithium Iron Phosphate)
- Battery voltage: 3.2V
- Light output: 29 lumens
- Run time (full battery): 6.5 hours
- Run time (per day of solar charging): 4.5 hours

(*courtesy d.light*)

Example—Sun King Pico

- PV rating: 0.38 W
- Battery rating: 470 mAh (Lithium Iron Phosphate)
- Battery voltage: 3.2V
- Light output: 23 lumens
- Run time (full battery): 6.6 hours
- Run time (per day of solar charging): 6.2 hours

source: sunking.com

Example—Barefoot GO 250

- PV rating: 2.7 W
- Battery rating: 3400 mAh (Lithium Iron Phosphate)
- Battery voltage: 3.2V
- Light output: 125 lumens
- Run time (full battery): 5.7 hours
- Run time (per day of solar charging): 5.5 hours

source: barefootpower.com

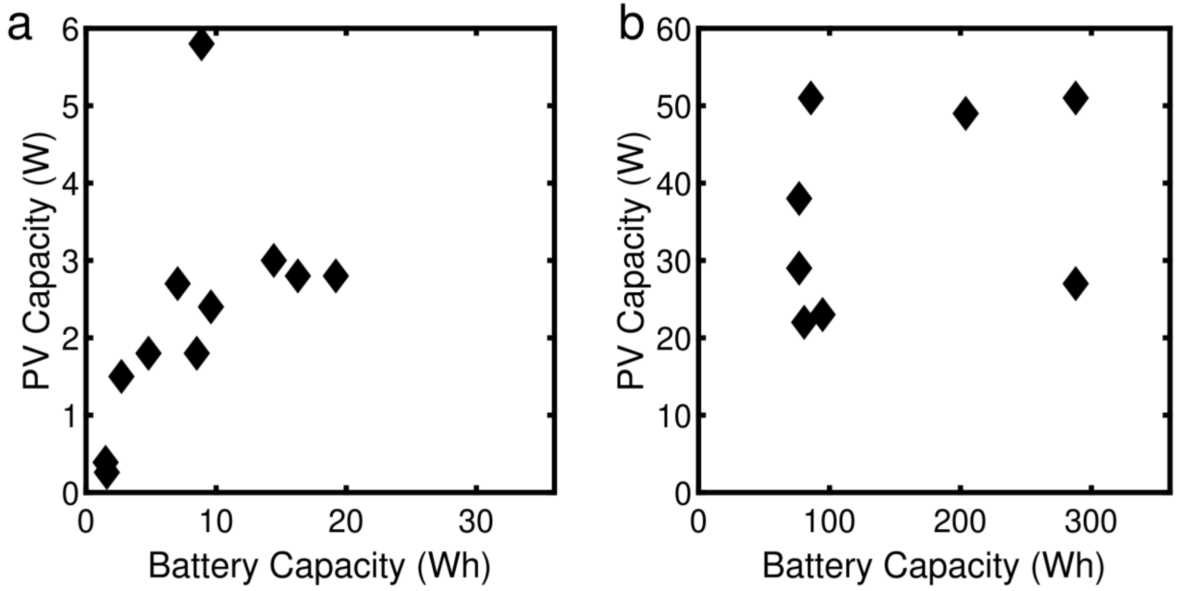
solar panel is separate

Example—Mpower M-120

- PV rating: 43 W
- Battery rating: 11 Ah
- Nominal voltage: 12.8V
- Battery chemistry: Lithium Iron Phosphate
- Energy provided per day: 107 Wh/day
- Light ports: 6
- USB ports: 1
- 12 V ports: 8

Solar Lanterns and SHS

- Typical price for SL and SHS range from US$3 to US$25 per PV Watt
- Typical battery to PV panel rating ratio (Wh/W): 3 to 4



Remote Data Capture and Control

- SHS often have remote monitoring and control capability
  - low connectivity requirements (2G)
- Typical data collected
  - state-of-charge
  - temperature
  - power output
- Uses
  - asset management
  - research and design
  - understanding user behavior
  - implementing business models

(*courtesy KiloWatts for Humanity*)

SHS Business Models

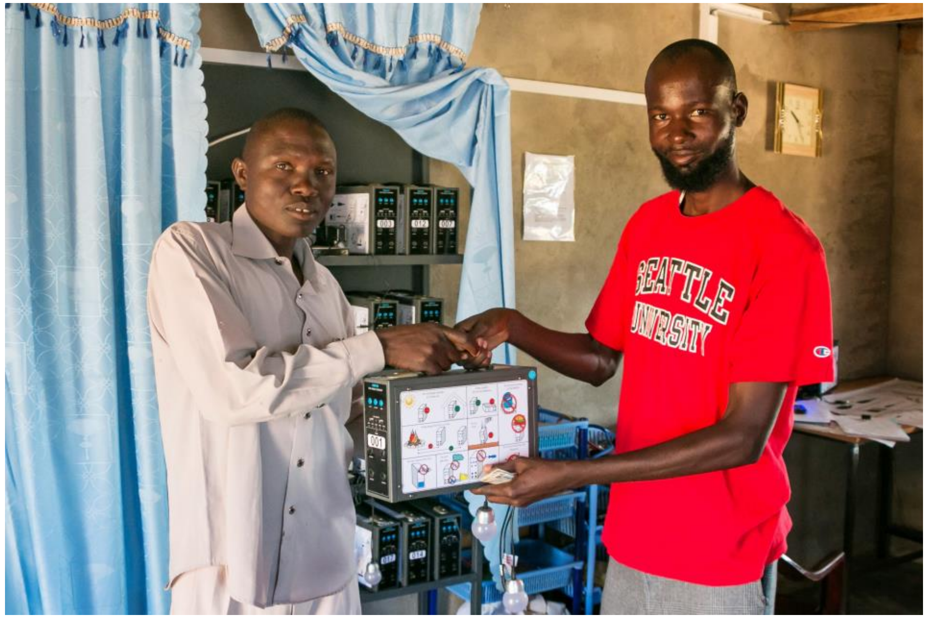
- Upfront cost of SHS (often +US$100) is a barrier to many
- Business models and payment options have evolved to lower this barrier
- Important considerations:
  - How to handle non-payment?
  - What happens in case of failure?
  - Who owns the SHS?

Rent-to-Own

- Periodic payments are made over a 6-24-month period
- After final payment, the customer owns the SHS outright
- Small deposit or upfront payment often required
- SHS might not be replaced by seller if it fails during the repayment period
- Seller must have a way to repossess or disable the SHS if customer misses payment(s)
  - remote disablement often used

Perpetual Lease

- Customer never owns the SHS
- Payments made periodically
  - can be a “per day” fee rather than per kWh fee
- SHS is replaced by the leaser as needed
- Seller must have a way to repossess or disable the SHS if customer misses payment(s)
  - remote disablement often used



(*courtesy Kilowatts for Humanity*)

SHS Payment Considerations

- Method:
  - cash to seller or agent
  - mobile money
- Frequency:
  - smaller, more frequent payments can be more manageable by customer but can be burdensome if cash is used
  - weekly or daily payments
- Amount:
  - cost-competitive with amount spent on kerosene or candles
  - often US$0.30 to US$2.00 per day depending on SHS size and payment terms

Post Pay Systems

- Basic Idea: customers pay based on actual consumption (plus fixed charges, VAT, etc.) after consumption has occurred
- Pros:
  - payment is linked to cost
  - incentive to conserve/make good use of energy
- Cons:
  - requires meters to be installed, maintained and read
  - bills must be sent to customers and debts collected
  - transparency--variability in bill may cause complaints
  - requires manual disconnection if customer fails to pay (and reconnection)

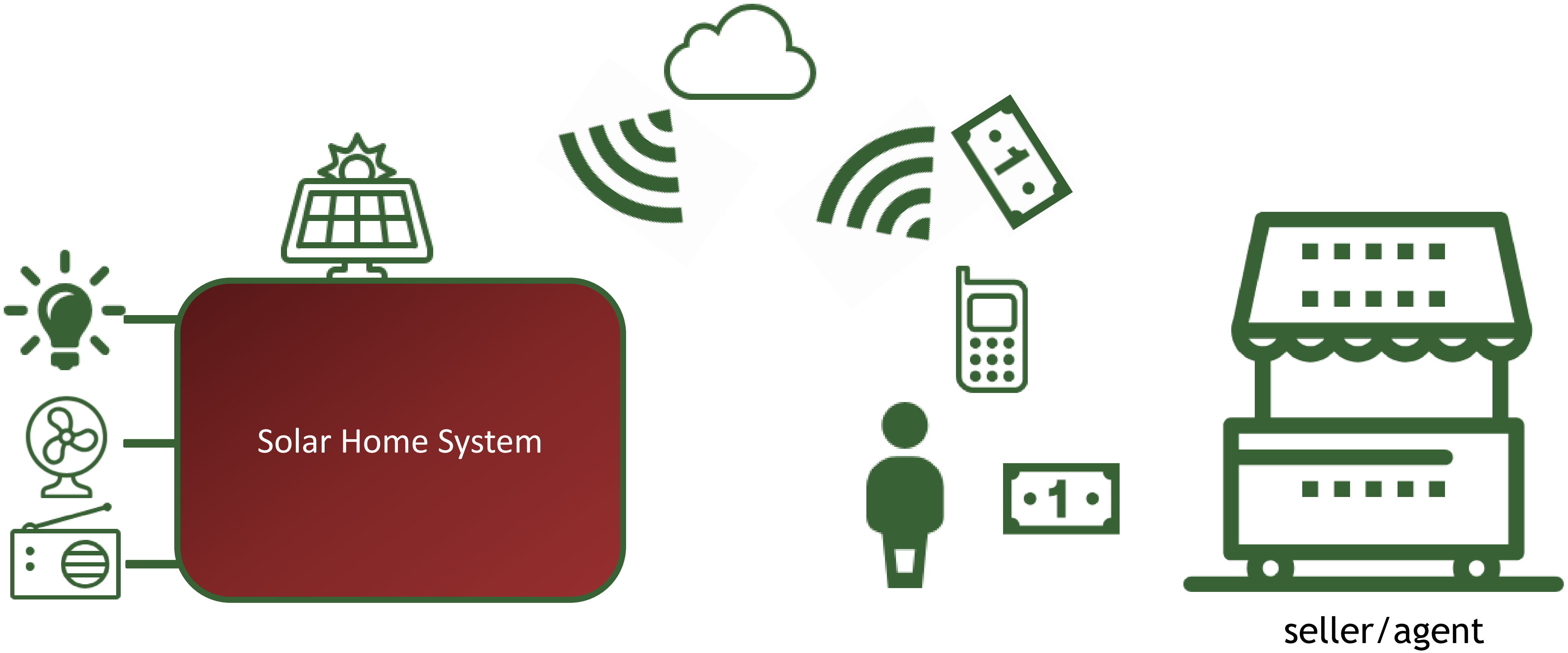
Pre-Pay Systems

- Basic Idea: customers pay for credit (kWh of electricity or days of use) before the energy is consumed; after the purchased energy is used, the SHS/SL disconnects user
- Similar to how mobile phone “talk time” and data are purchased and utilized
- Pre-pay systems have been in use in the UK for 80 years, and in Africa since the 1980s

Pre-Pay Systems: mini-grids

- Primary reason for adopting most pre-pay systems is to reduce debt owed to mini-grid operator
- Meters become the intermediary between the operator and the customer
- Post-pay: operator supplies electricity to customers and must collect the debt owed, customers are often high credit risks and some debts are slow to be paid or are never paid
- Transparency: customers can monitor their consumption (the meters often have digital displays of remaining credit or kWh)
- Billing: using post-pay, customers can be surprised by the bill

Pay-As-You-Go Solar



Summary

- Solar Lanterns and Solar Home Systems offer lower-tier, but still meaningful, electricity access
- Lighting and recharging provided by SL and SHS can save households money
- Several business models and payment methods: outright purchase, rent-to-own, perpetual lease, pay-as-you-go, etc.