

Solar PV: An Introduction

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Teaching Associate

EE4511: Renewable Generation and Smart Grid

19 January 2023



NUS
National University
of Singapore

National University of Singapore

| Course description

► Solar Energy: Photovoltaics

- Thursday 19th Jan
 - Thursday 26th Jan
 - Monday 30th Jan
 - Thursday 2nd Feb
 - Monday 6th Feb
- 
- Introduction
 - Solar cells and modules
 - Solar PV systems
-
- Mondays are online – Zoom – 2 hours
 - Thursdays are face to face – EA-06-03 – 1 hour

Contact

► Email

- carlos.rodriguez@nus.edu.sg
- Subject: “EE4511...”

| Site visit

- Solar photovoltaic (PV) system at Marina Barrage:
~mid Feb



PV: AN INTRODUCTION

PV in time

1839

Photovoltaic effect
discovered by Alexandre
Becquerel

1905

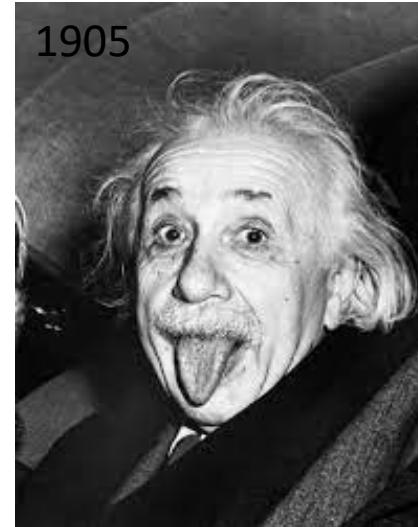
Photoelectric effect
explained by Albert Einstein

1954

Bell Labs invented usable
Silicon solar cell > 5%
efficiency, US

1958

PV in space of < 1Wp US
space satellite, Vanguard 1



1954



1958



PV in time

1960

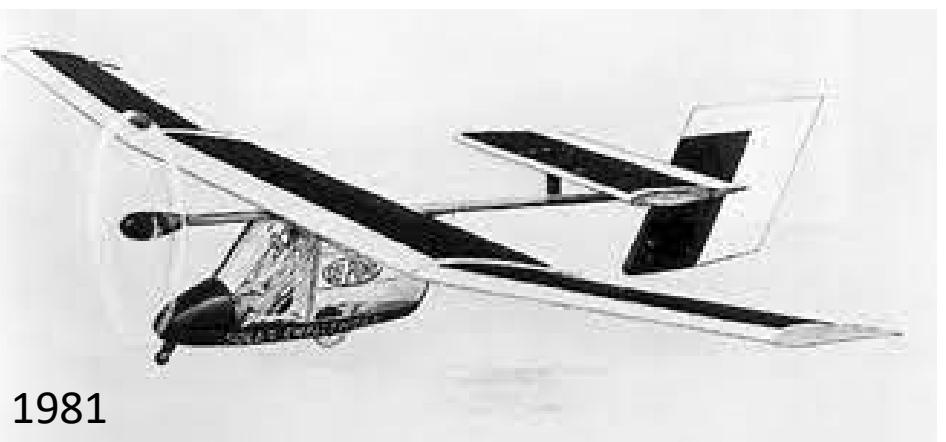
World's largest PV of 242 Wp
at lighthouse, Japan

1964

Nimbus Satellite with
470 Wp, NASA

1981

First solar powered plane
“Solar Challenger”, US



PV in time

1982

First solar powered car,
Australia

1982

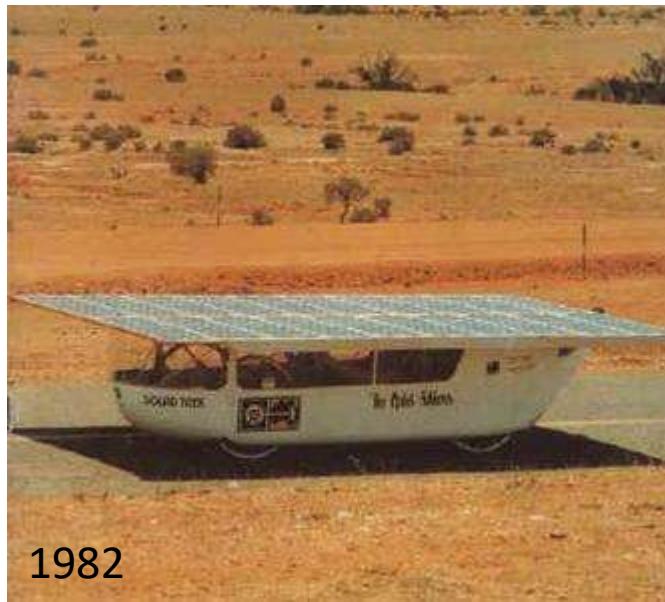
First MWp PV system, US

1985

>20% Silicon cell efficiency,
University of New South
Wales Australia

1994

>30% tandem cell efficiency,
NREL, USA



PV in time

2007

First floating PV of 20 kWp,
Japan

2008

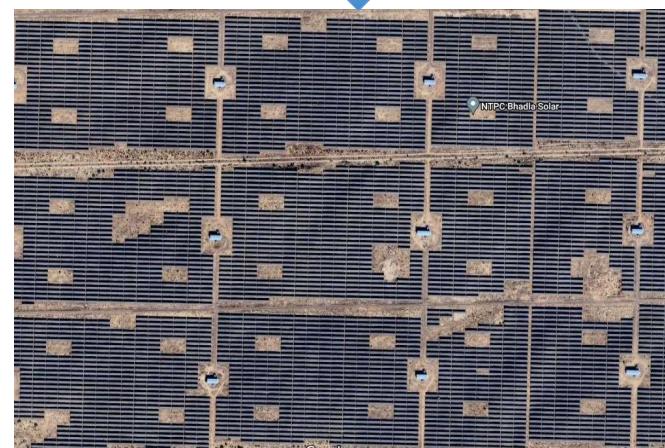
Creation of the Solar Energy
Research Institute of
Singapore

2017

World's largest PV
installation of 2.25 GWp,
India

2021

Singapore's largest PV
installation of 60 MWp,
Tengeh Reservoir



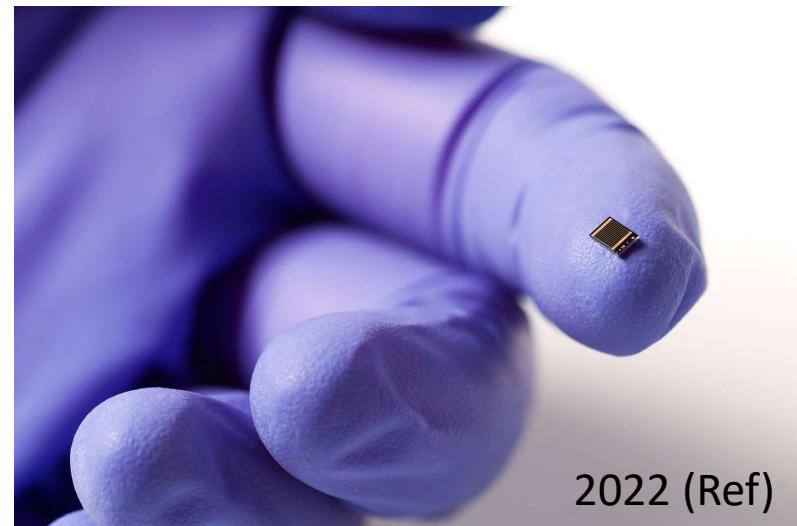
| PV in time

2022

Highest cell efficiency of
47.6% (tandem), Fraunhofer
ISE, Germany

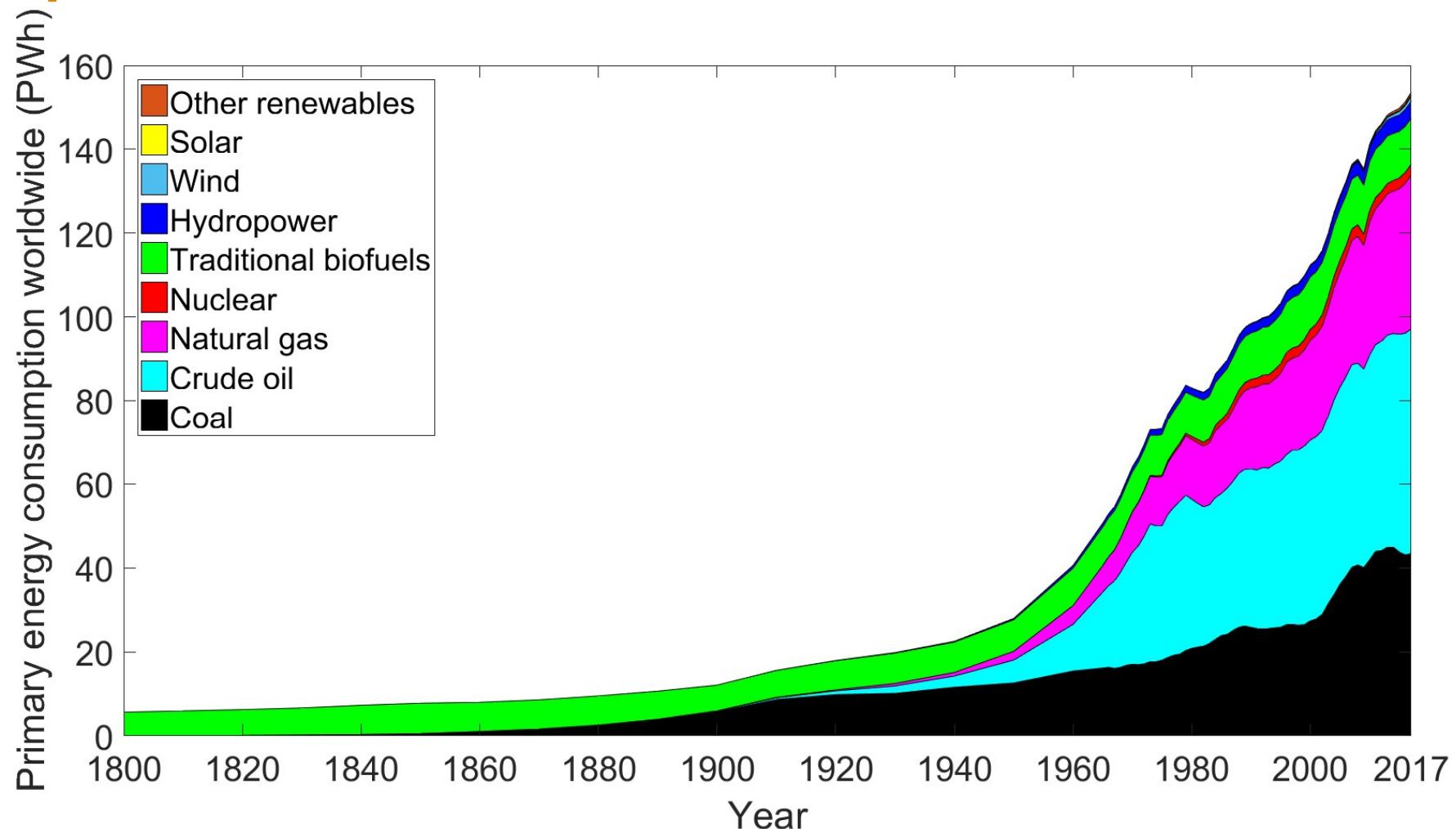
2023

More than 1 TWp of PV
worldwide



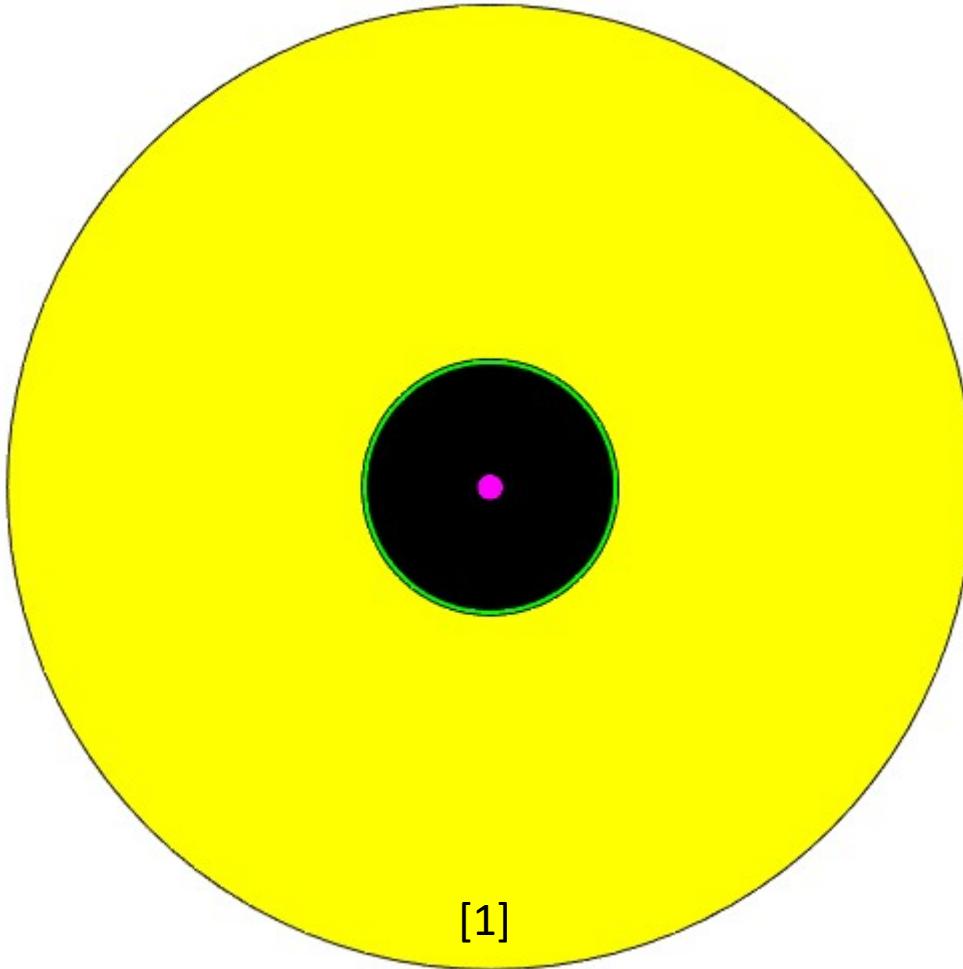
2022 (Ref)

Historical energy trend



[1] V. Smil, ABC-CLIO, 2017

Solar potential



- Yearly world energy demand ($L \approx 18.5\text{TWy}$)
- Non renewable reserves ($\sim 85L$)
- Yearly energy potential from renewable sources except solar ($\sim 8L$)
- Yearly potential from solar energy ($\sim 1200L$)

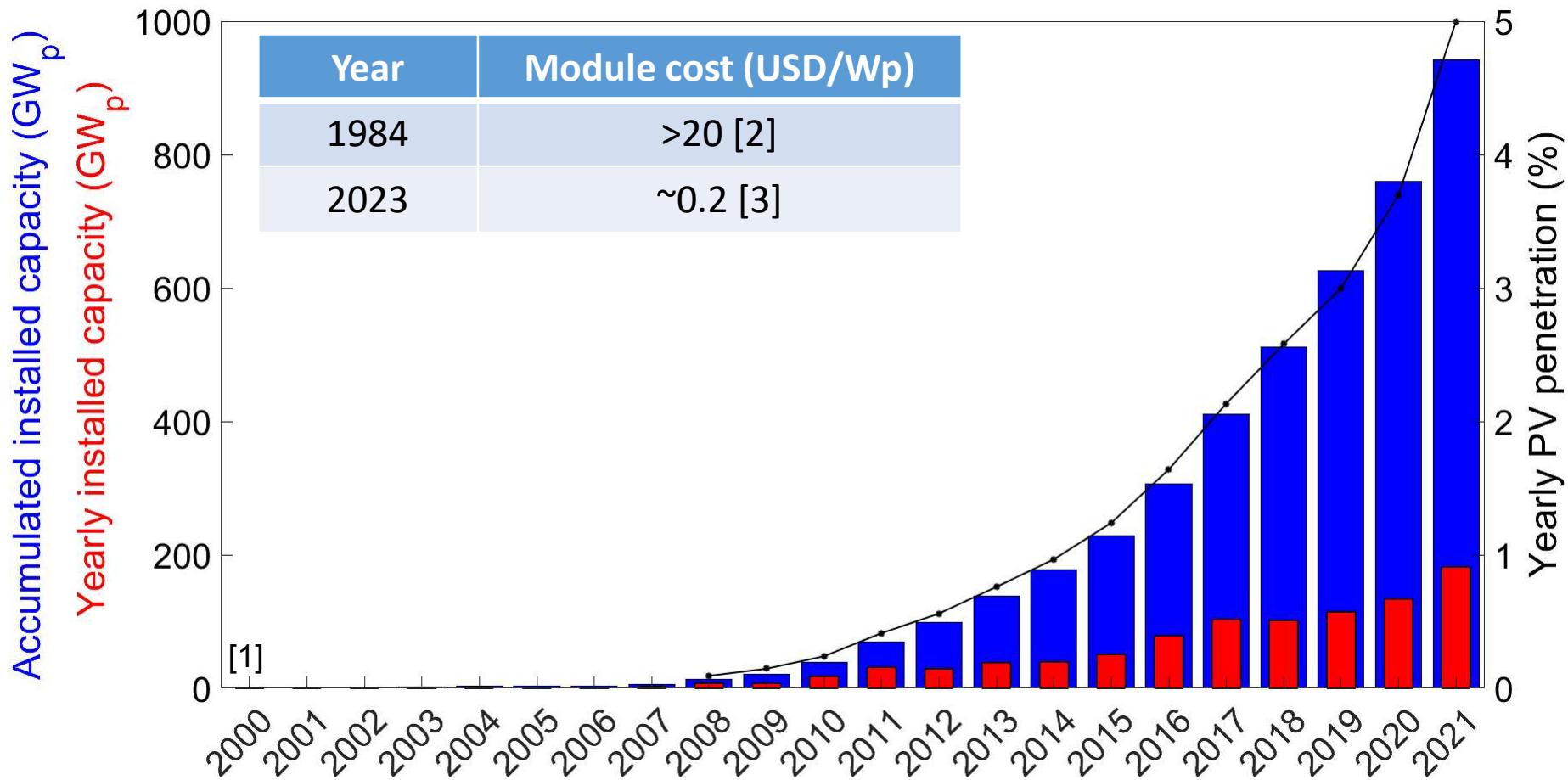
Source	Years of KNOWN reserve left [2]
Natural gas	49
Oil	54
Coal	139

[1] M. Perez, Natural Gas, 2015

[2] BP-Global 2020

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PV capacity: ~942 GW_p till 2021



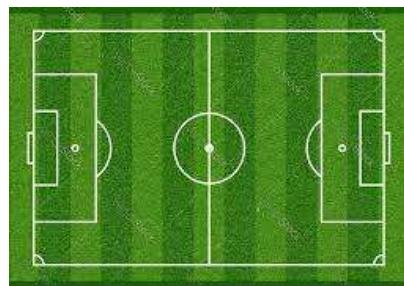
[1] International Energy Agency (IEA), snapshot of global PV markets (2019, 2020, 2021, 2022)

[2] V. Sivaram and S. Kann, "Solar power needs a more ambitious cost target," Nature Energy, 2016

[3] PVinsights, "Solar PV module weekly spot price," 11 Jan, 2023

PV capacity: ~942 GWp till 2021

- ▶ Watt peak (Wp) is a measure of PV power produced under Standard Testing Conditions
- ▶ 1 MWp → ~2,500 solar panels → ~1 football field



- ▶ ~942 GWp → ~2.4 BILLIONS solar panels → ~4,800 km² → ~6.6 times Singapore!

Note: Solar panels assumed of 400 Wp each

Renewable targets

Country	Renewable target	Aimed year
Canada	100%	2050
Switzerland	100%	2050
United Kingdom	100%	2050
Finland	100%	2035
Chile	70%	2030
Germany	40-45%	2025
India	40%	2030
China	35%	2030
Singapore	2.5 GWp by 2025 and 3 GWp by 2030	

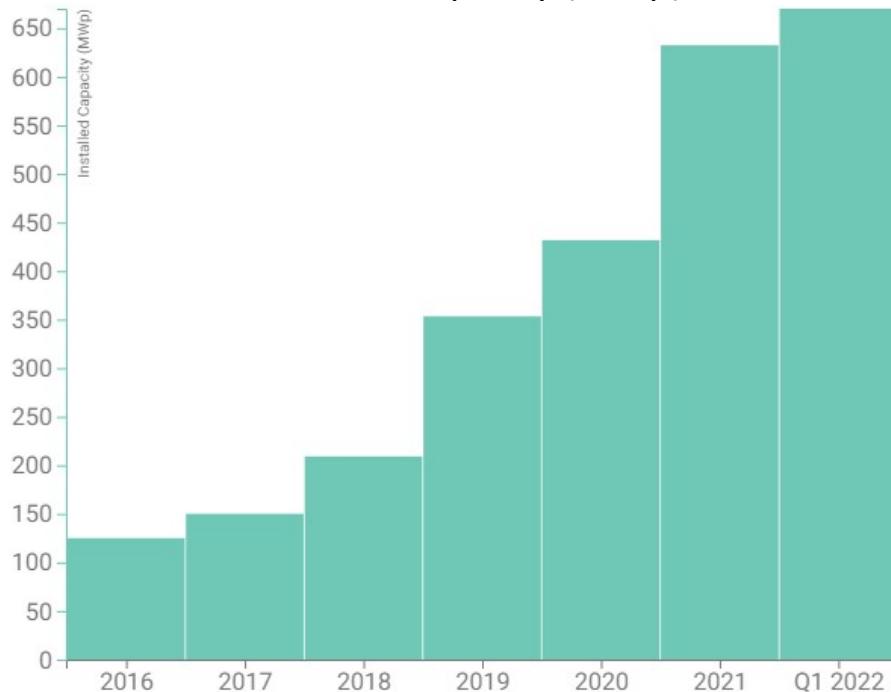
- ▶ Singapore renewable target focuses in PV

[1] https://en.wikipedia.org/wiki/Mandatory_renewable_energy_target
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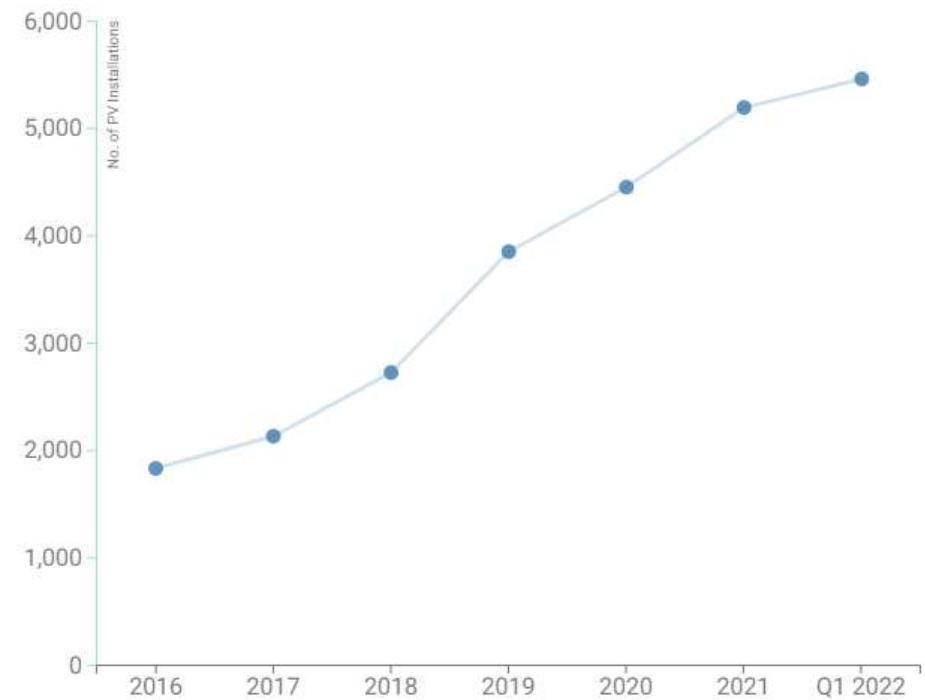
Singapore + PV

► As of Q1-2022: 670 MWp & 5,455 PV installations

Installed capacity (MWp)



No. of PV installations



Singapore + PV

► For which user has most PV been installed?

1. Residential – Private
(e.g. houses)

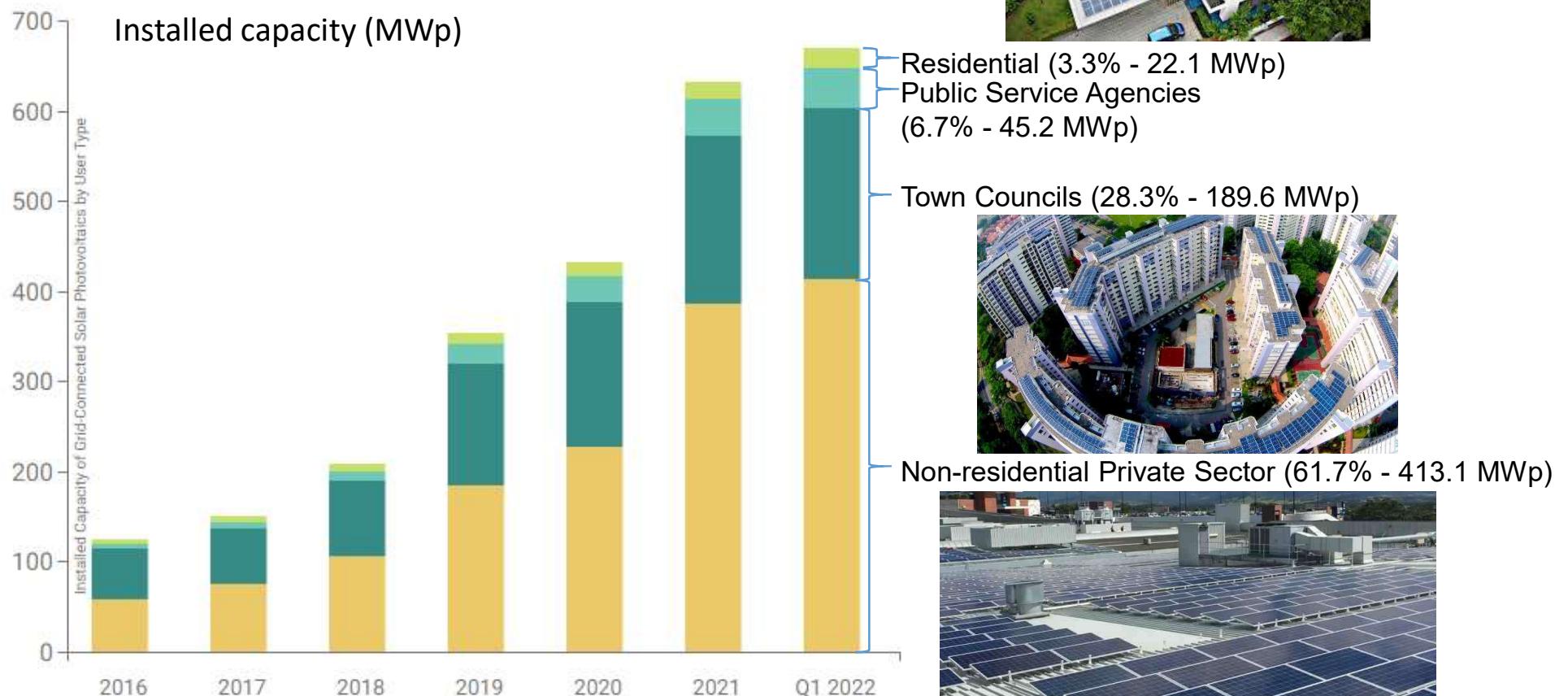
2. Non-Residential – Private
(e.g. factories, industries)

3. Town Councils
(e.g. HDB)

4. Public Services Agencies
(e.g. schools, hospitals, etc.)

Singapore + PV

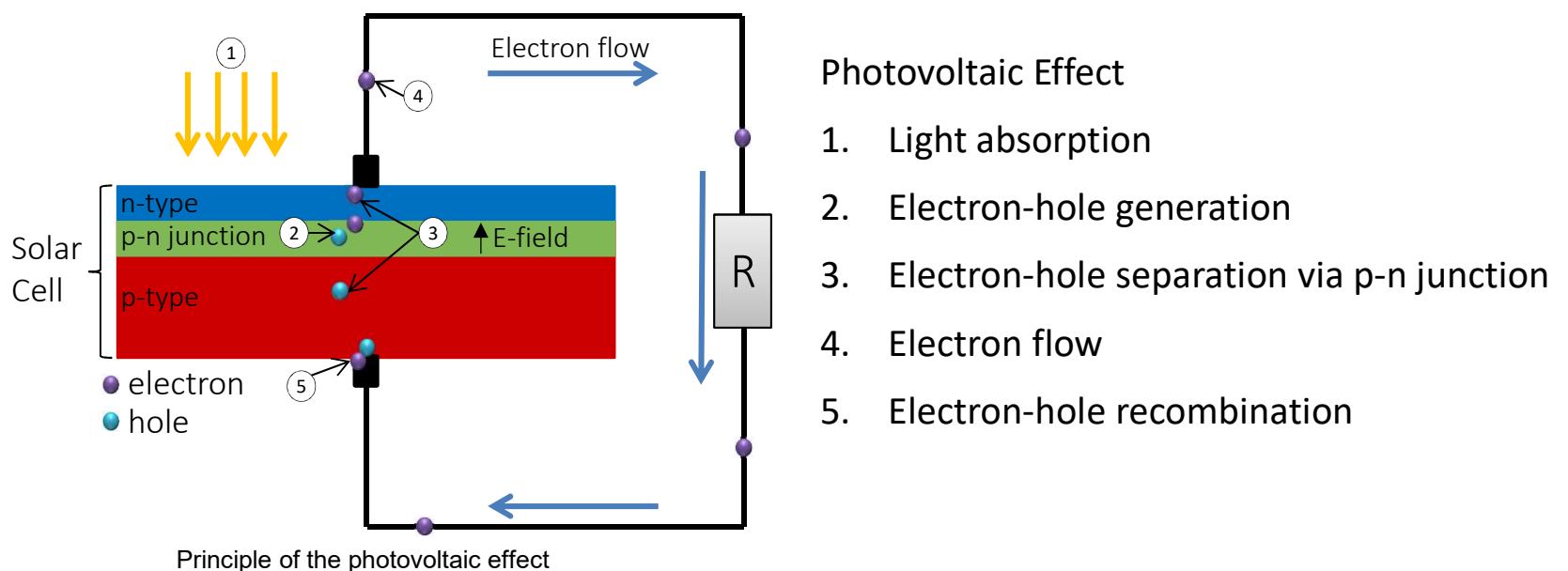
Installation by user



[1] EMA <https://www.ema.gov.sg/singapore-energy-statistics>
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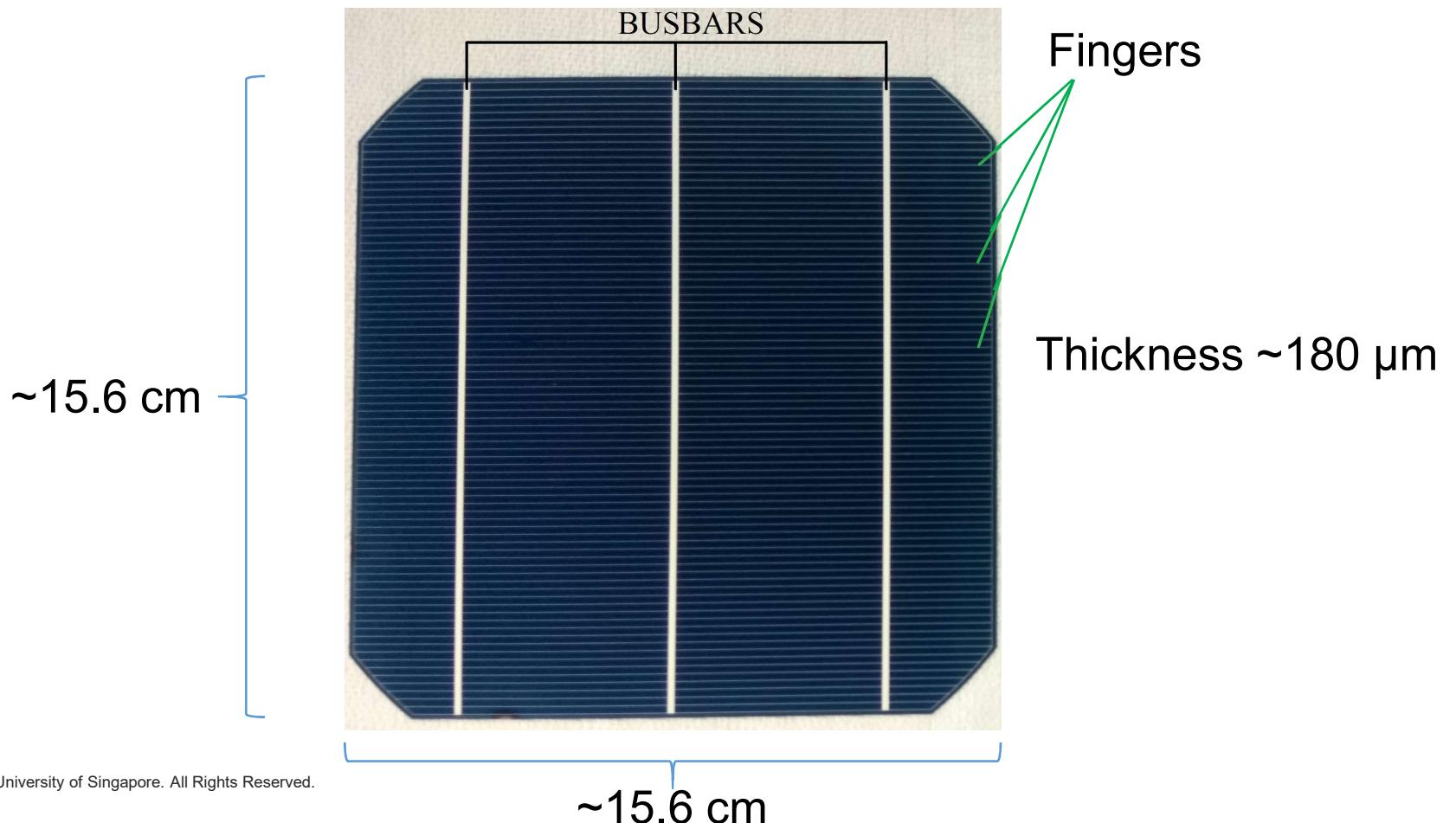
Photovoltaic (PV) Principle

- ▶ Photo: Light Voltaic: Voltage
- ▶ Direct conversion from light energy into electrical energy



Solar cells

- Basic unit at which the photovoltaic effect takes place



Solar cells

- ▶ A solar cell is normally a p-n junction semiconductor
- ▶ An LED is a light emitting diode
- ▶ A diode is normally a p-n junction semiconductor
- ▶ Is an LED a solar cell?
- ▶ Is a solar cell a diode?



THANK YOU