Evaluation of moisture ingress through edge sealants for floating PV applications

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SOPHIA PV-Module Reliability Workshop
June 30th, 2022

Department of Solar Power Systems at IFE

UTILITY SCALE PV

DISTRIBUTED PV

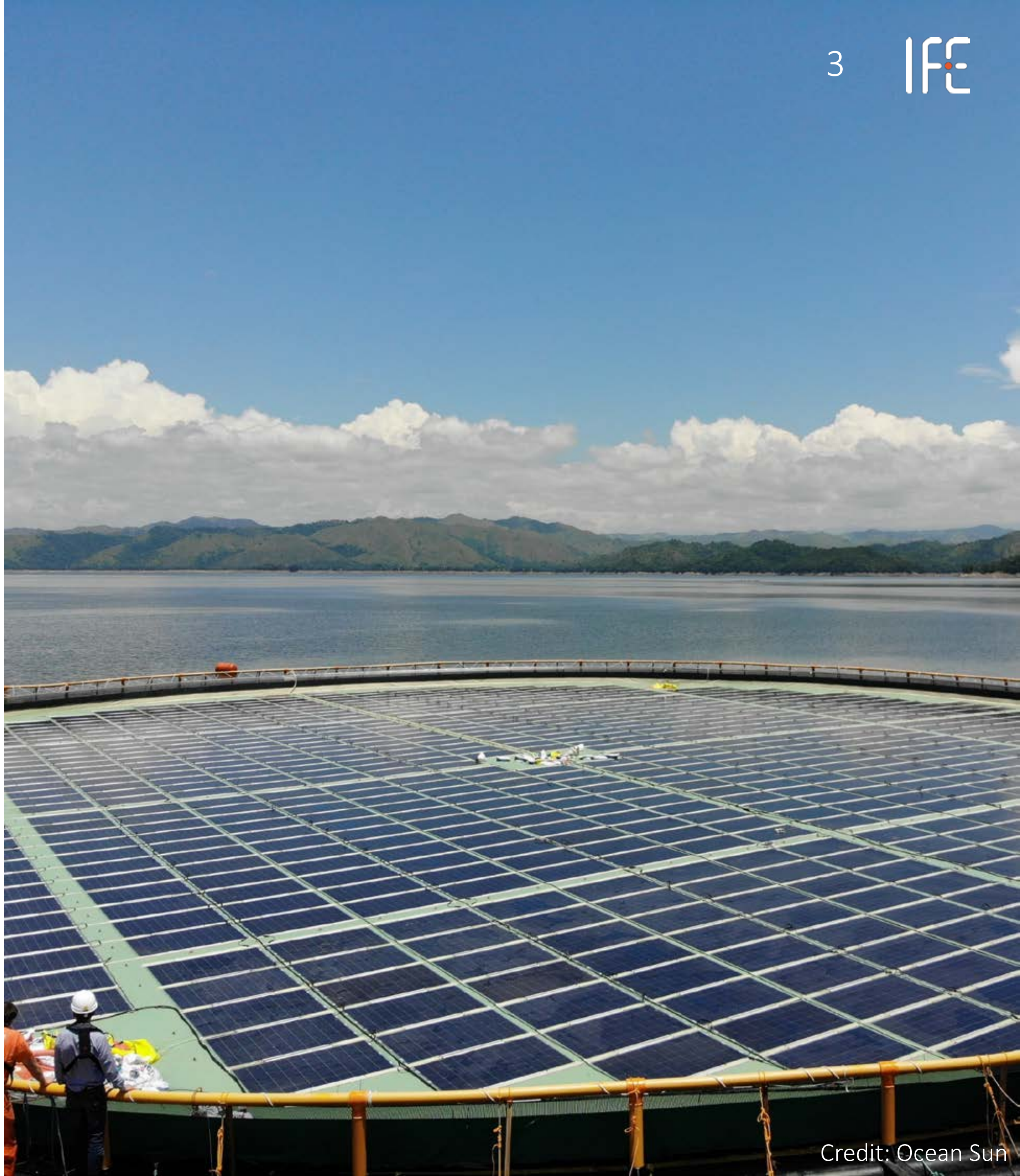
FLOATING PV

PV module laboratorium & test sites

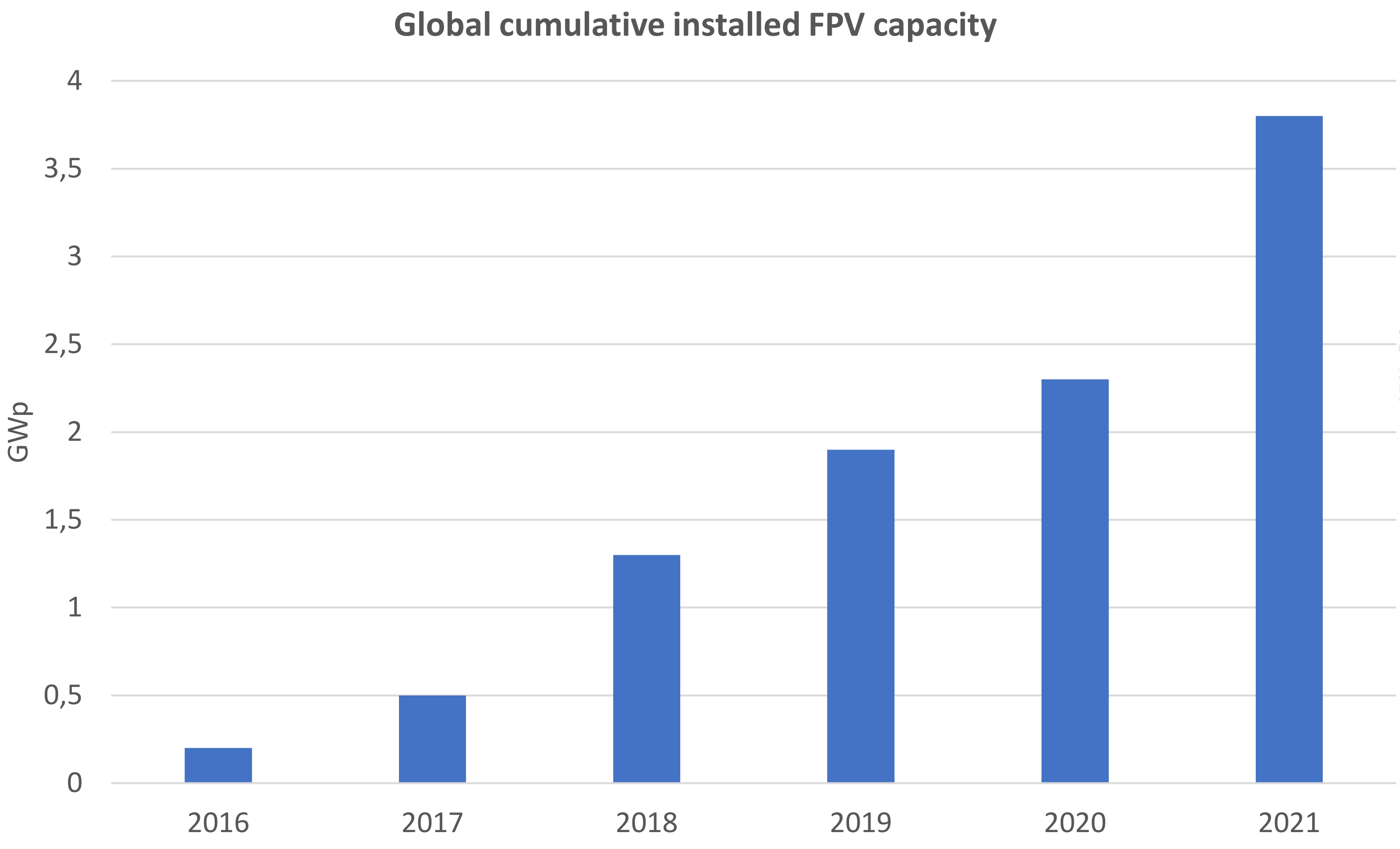
- Energy yield assessment
- Reliability
- O&M
- Time series analysis
- Thermal and mechanical modelling
- Energy system analysis
- Prototype development

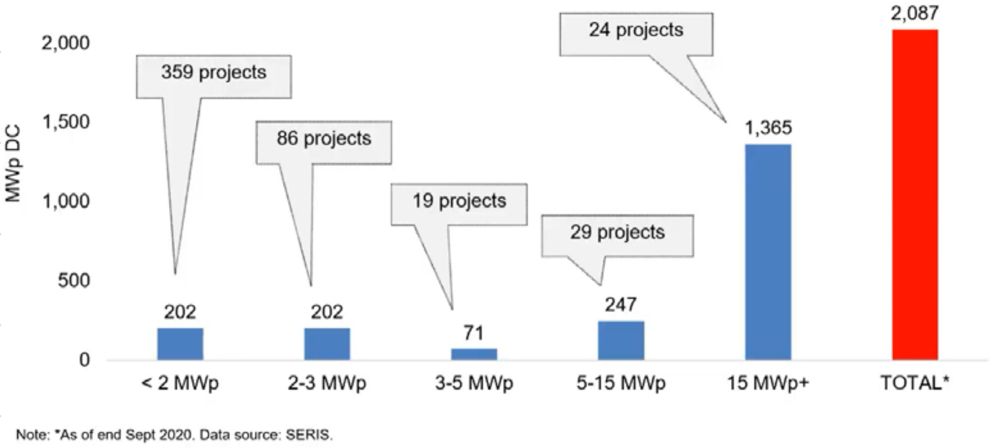
Floating photovoltaics (FPV) at a glance

- Can exploit water surfaces for electricity production
- Has *potential* for increased yield due to lower module temperature
- Has *potential* to increase use of existing infrastructure through co-location or hybridization
- Can *likely* reduce evaporation and algae growth
- Altered stressors *could* affect module lifetime



The global FPV market

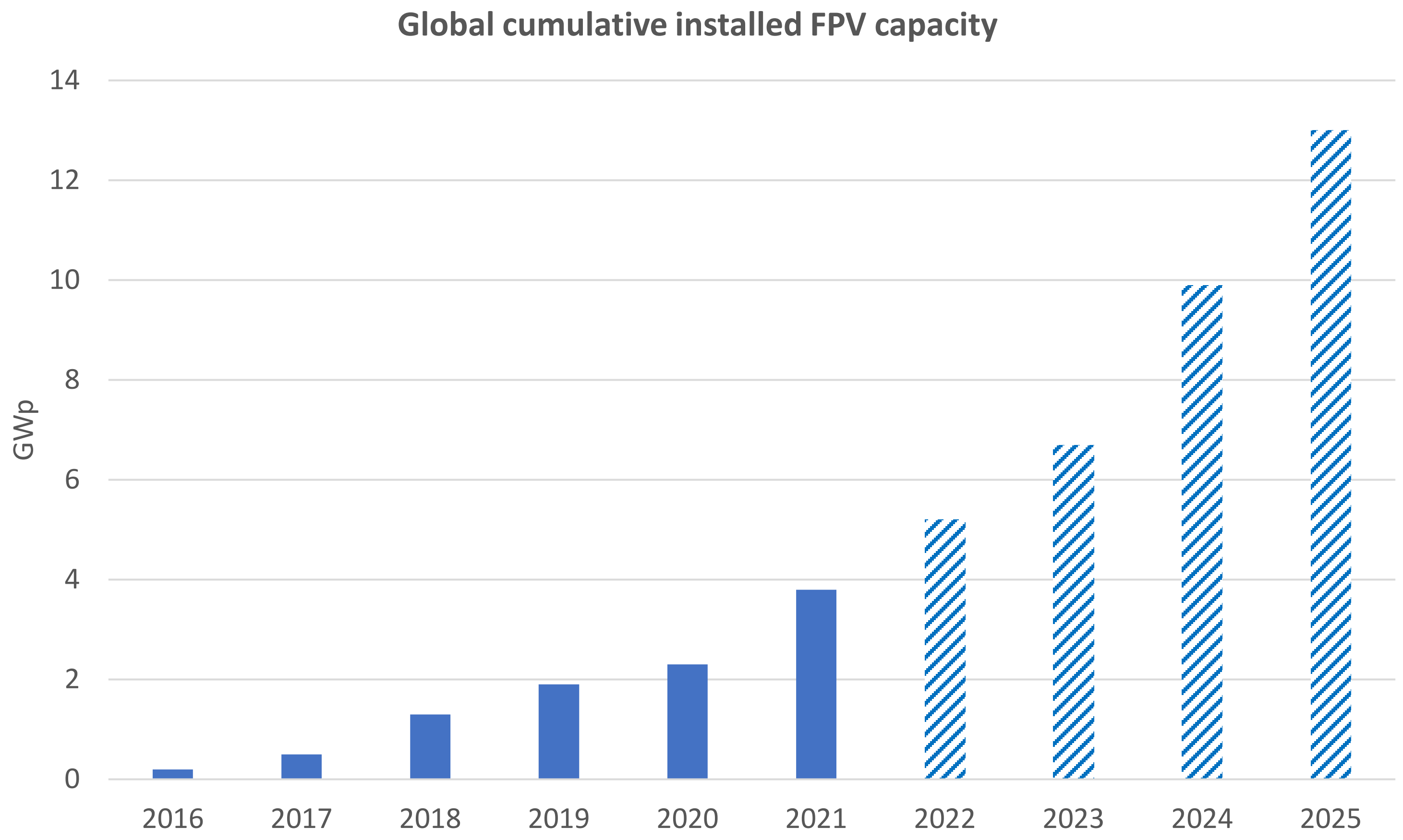




- More than 510 projects in operation
- Mostly small-scale systems
- 63% of installed capacity is in China

Source: Deloitte

The global FPV market



- 3 to 7.5 TWp potential on hydro dams[1]
- 0.4 to 4.0 TWp potential on man-made reservoirs[2]
  - 4 TWp represents 16% of world electricity generation in 2018 (IEA)

Source: Deloitte

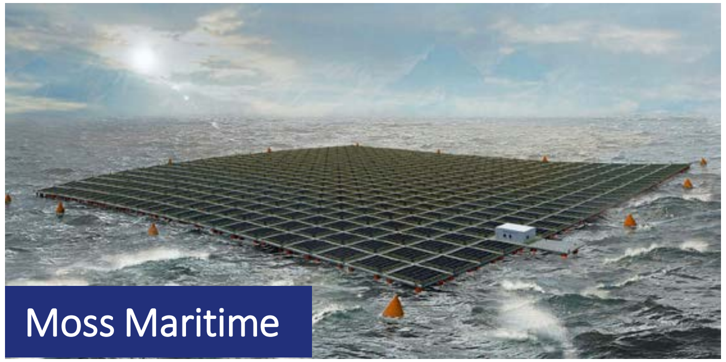
1. N. Lee et al. / Renewable Energy 162 (2020)
2. Where sun meets water, World bank, 2019

Main FPV markets

In land water bodies

Almost all current commercial projects are here
Calmer conditions -> fewer critical parameters

Near shore/offshore



Increasing interest as the technology is progressing
Relevant markets: coastal cities and islands
Norwegian industry well positioned

Hydro/FPV hybridization

Increased potential benefits (infrastructure, compensation of variability)
Increased system complexity

CIGS solar panels for o

A Dutch consortium is testing a 20 kW pilot float
applications with CIGS solar modules developed
Midsummer. The panels consist of 144 solar cell
485 W of capacity.

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Image: TNO

Puffer fish insp structure

With a new system for floating p
want to make the application ch
somewhat reminiscent of a puffe

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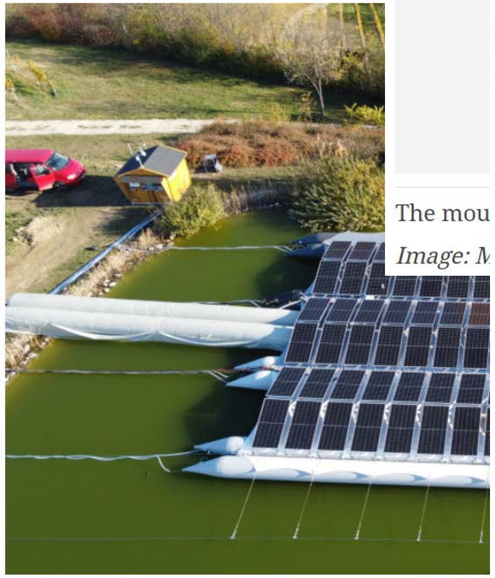

The prototype in Hungary .

Image: sbp Sonne

Floating PV mount harsh climatic con

Developed by Chinese specialist Mibet, t
endure wind and snow loads of up to 42
environments. It was recently deployed
may reach as low as 40 degrees Celsius.

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TECHNOLO

The mou

Image: M

New tech to re floating PV arr

French start-up HelioRec has de
more weight and increase its sta
product can be 3.5 times more s

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MODULES & UPSTREAM MANUFACTURING | TECH

The floater is made of with linear low-density polyethyl

Image: Heliorec

New floating PV mounting structure from Austria

The floater consists of a structure made of HDPE plastic which is claimed to withstand
waves of up to 3
Austrian tech co
onshore or offsh

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COMMERCIAL & INDUSTR | AUSTRIA

The floater is asse

Image: SolOcean

Trimaran-shaped floating PV system design from Spain

The proposed system architecture is claimed to offer more stability compared to conventional floating structures and reduces by up to 93% the contact area of the system with the water. The first system prototype was recently developed on a water reservoir in Alava, in the northeastern territory of the Basque Country.

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Emica Solar pilot installation in Alava, Spain.

Image: Emica Solar

What stressors affect a PV module?

The stressors affecting a PV module:

- Temperature ←
- Humidity ←
- Actinic (UV-)radiation
- Mechanical loads ←
- High voltages
- Corrosive compounds
- Abrasive loads ←
- Shading ←
- Wildlife ←
- +++

Which of these are different for FPV compared to ground-based PV?

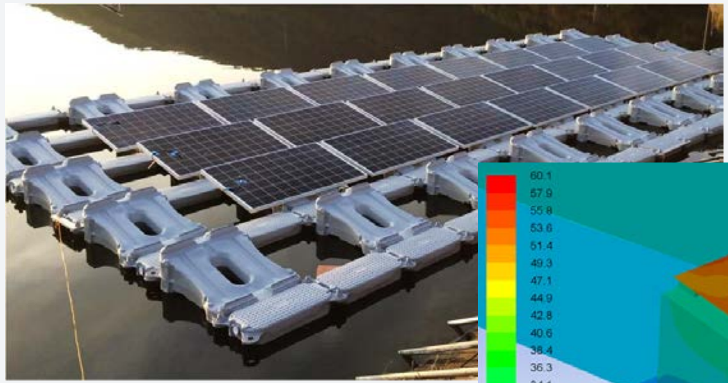
↓

Highly floater-technology-dependent

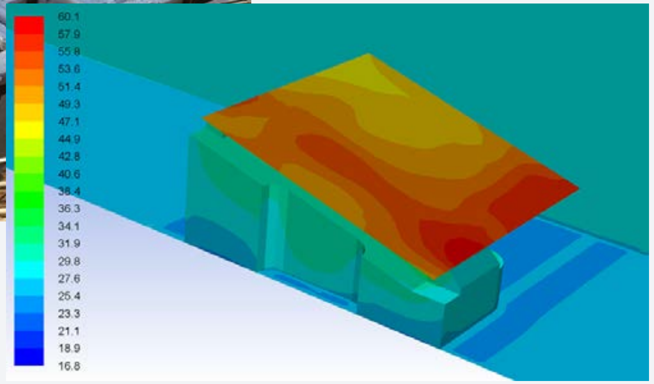
Image credits:
[1] Where sun meets water, World bank, 2019
[2] Dörenkämper et al., Solar Energy, 2021
[3] oceansun.no

Operating temperatures of FPV

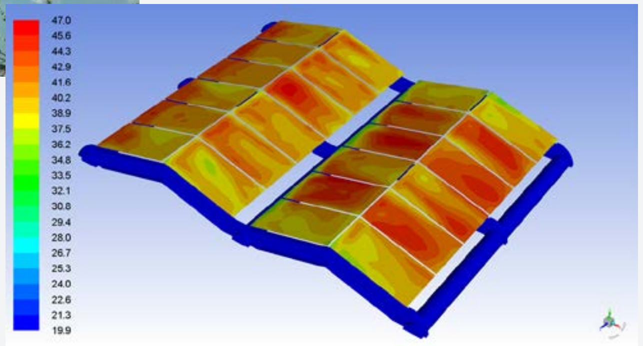
- High operating temperatures and rapid temperature fluctuations act as stressors
- “Cooling effect” typically mentioned as an advantage of FPV
- Looked at FPV operating temperatures through
  - System measurements
  - Developed heat balance model
  - Computational Fluid Dynamics (CFD) simulations



Ciel et Terre

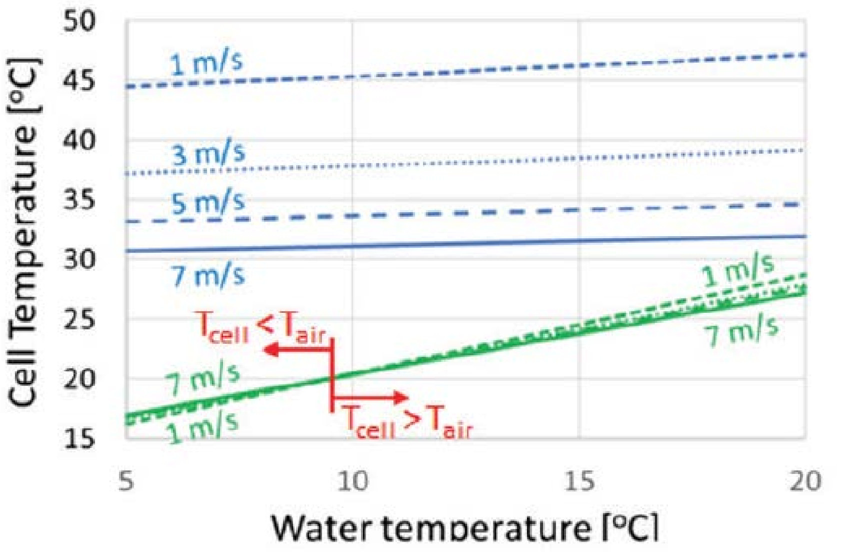


Current Solar



* T. Kjeldstad, D. Lindholm, E. Marstein, J. Selj. *Cooling of floating photovoltaics and the importance of water temperature.* Solar Energy 218 (2021), pp. 544-551.
* D. Lindholm, T. Kjeldstad, J. Selj, E. Marstein and H. Fjær. *Heat Loss Coefficients Computed for Floating PV Modules.* Prog Photovolt Res Appl. 29 (2021), pp. 1262-1273.
* D. Lindholm, J. Selj, T. Kjeldstad, H. Fjær, and V. Nysted. *CFD modelling to derive U-values for floating PV technologies with large water footprint.* Solar Energy 238 (2022), pp. 238-247.
* T. Kjeldstad, V. Nysted, M. Kumar, S. Pinto, G. Otnes, D. Lindholm, and J. Selj. *The performance and amphibious operation potential of a new floating photovoltaic technology.* Solar Energy 239 (2022), pp. 242-251.

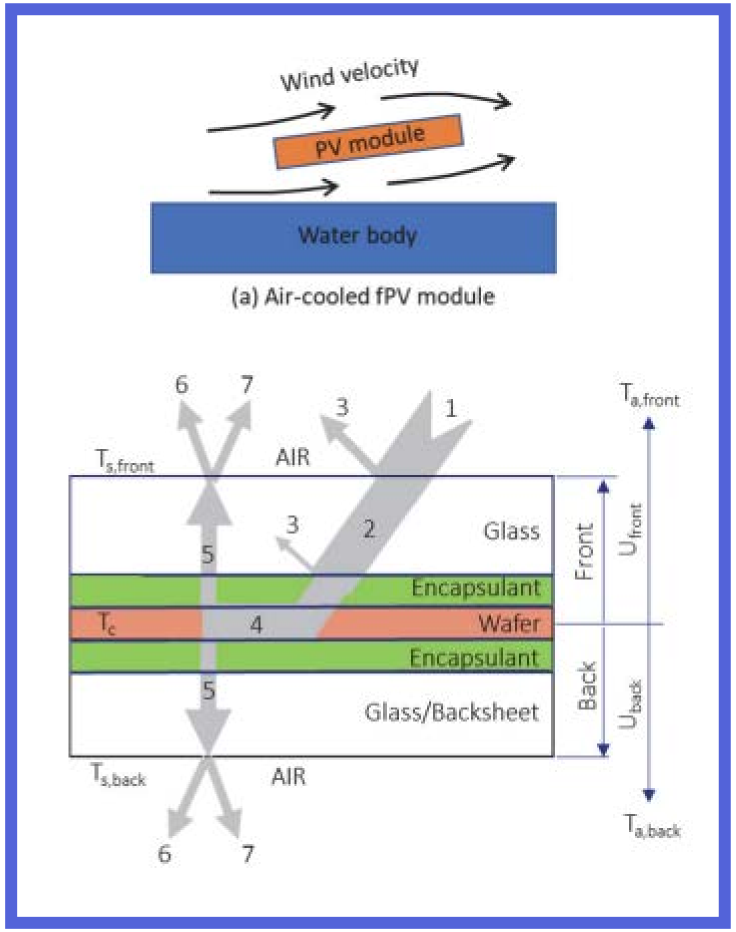
Heat balance model for different FPV cases



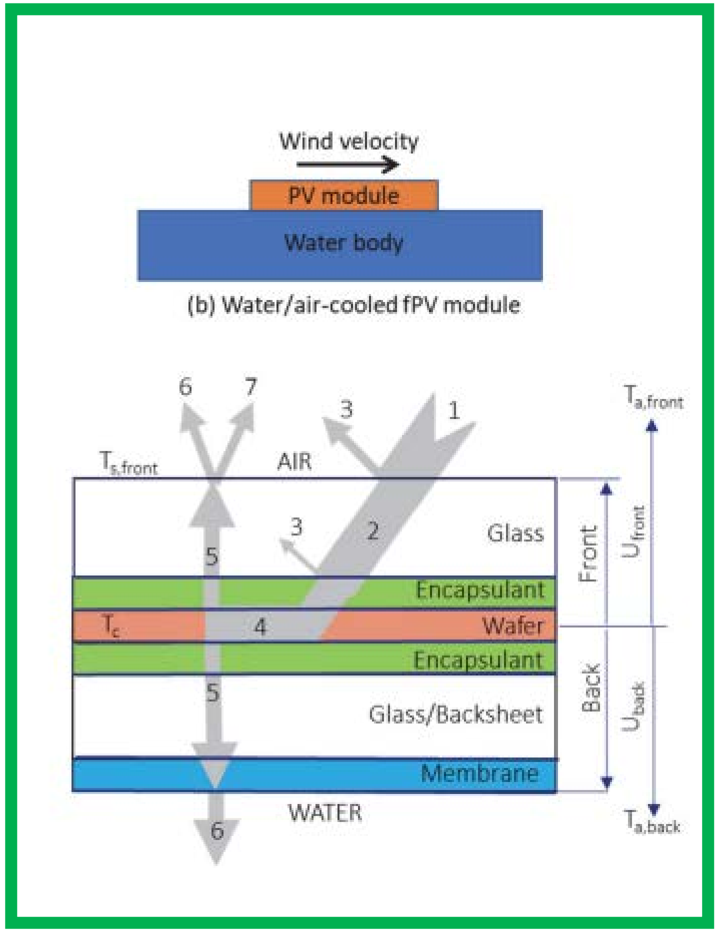
Air temperature = 20°C

- For air-cooled system, water temperature has a small impact on cell temperature, but wind is important
- For water-cooled system, the water temperature plays larger role than wind

Air-cooled



Water-cooled



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Differences between water-cooled and air-cooled

Water-cooled:

- Thermal contact with water – heat exchange with water
- Less thermal fluctuations, lower overall temperatures

Air-cooled:

- Lower cooling effect than suggested by early literature
- Lower overall air temperature and larger wind speeds can result in lower operating temperatures than on land
- Degree of cooling dependent on the type of floater
- Variations also expected within the system

Ocean Sun

Ciel et Terre

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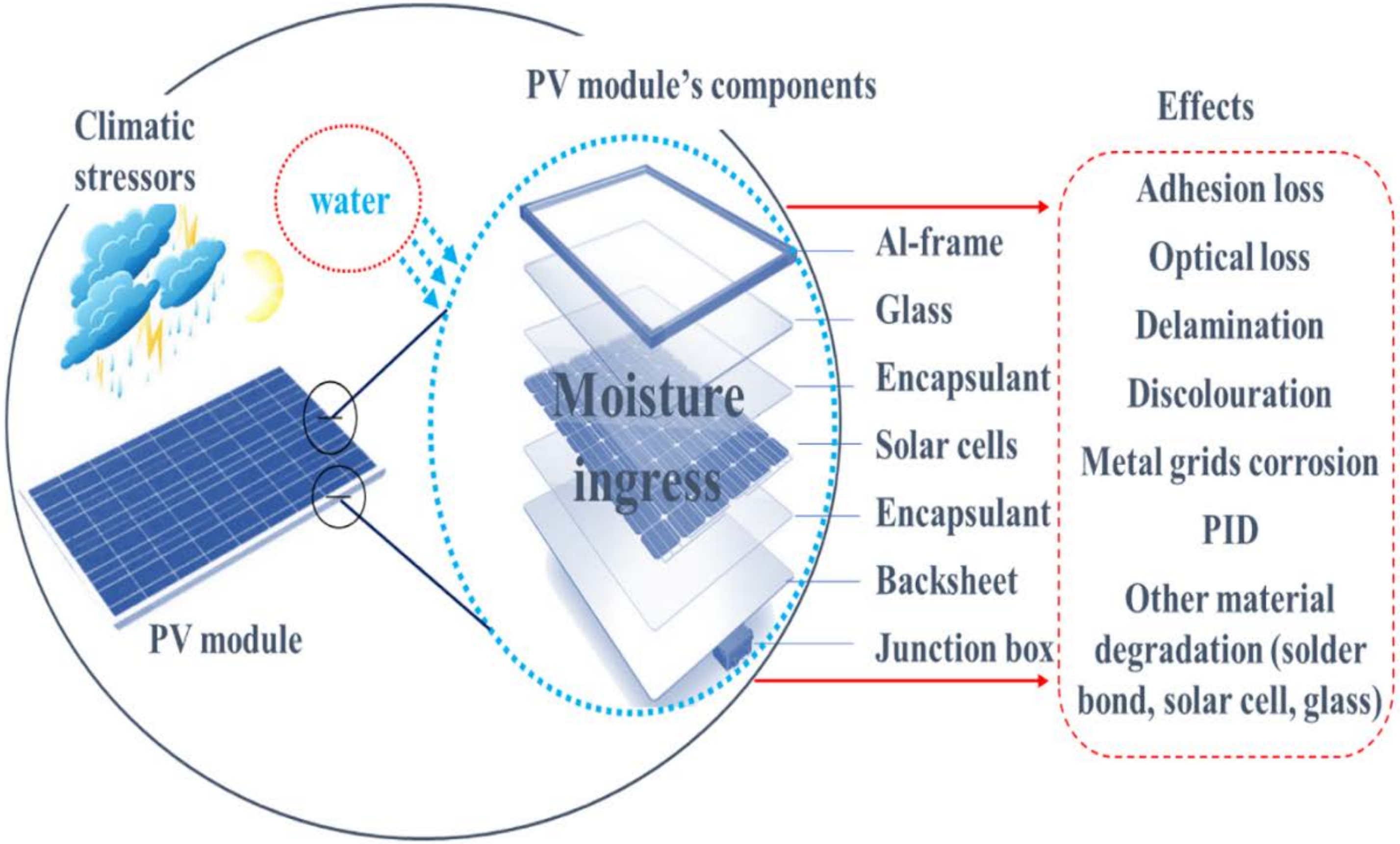
Moisture ingress in PV modules



Segbefia, O. K., Imenes, A. G., & Sætre, T. O. (2021). Moisture ingress in photovoltaic modules: A review. In *Solar Energy* (Vol. 224, pp. 889–906). Elsevier Ltd. https://doi.org/10.1016/j.solener.2021.06.055

Moisture ingress: ground-mounted versus floating PV

- Four relevant differences in environmental conditions:
  - Temperature
  - Level of humidity
  - Presence of liquid water
  - Presence of salt

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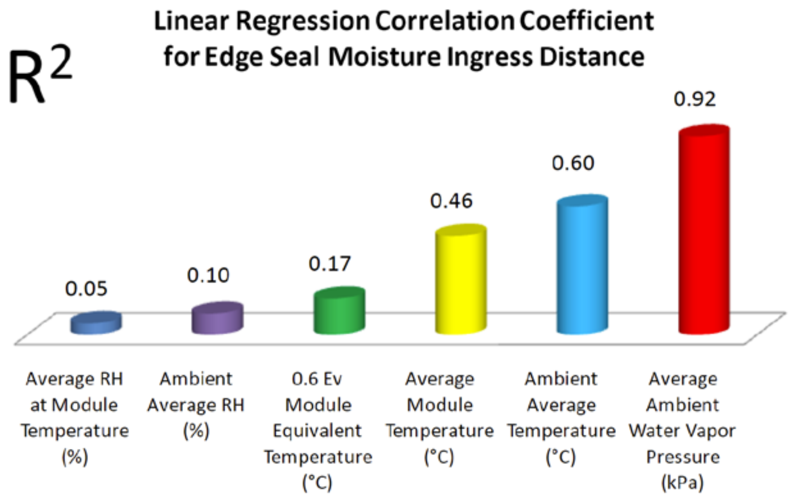
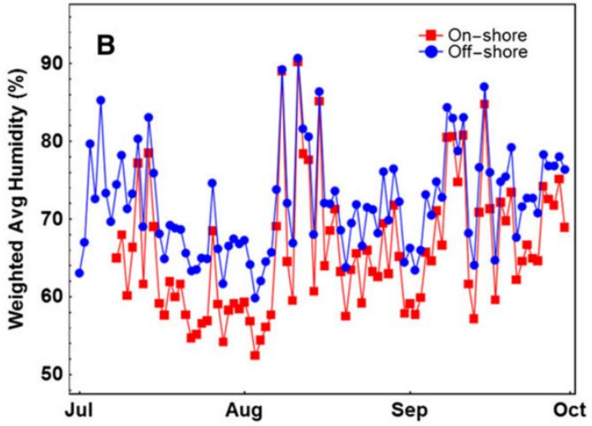
Moisture ingress: ground-mounted versus floating PV

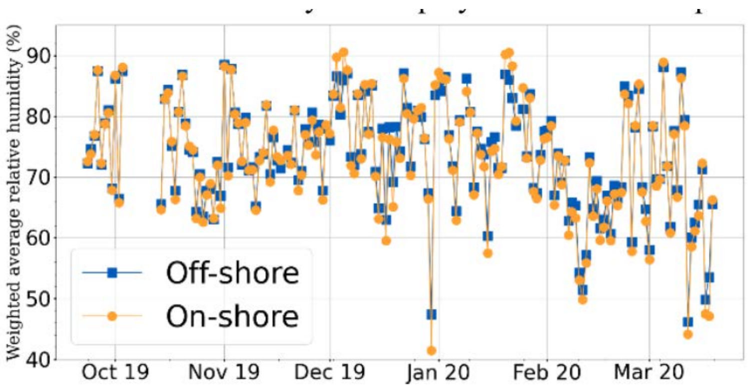
- Humidity:
  - Most important coefficient to determine moisture ingress
  - Somewhat higher on water than on land
    - On-shore taken close to lake
  - ➢ Moderate higher degradation for FPV compared to ground mounted PV expected



Tropical climate



Moderate climate



Top: Kempe, M., Kurtz, S., Wohlgemuth, J., Miller, D., Reese, M., & Dameron, A. (2011). *Modeling the Ranges of Stresses for Different Climates/Applications (Presentation)* (No. NREL/PR-5200-52312). National Renewable Energy Lab.(NREL), Golden, CO (United States).
Bottom left: Liu, H., Krishna, V., Lun Leung, J., Reindl, T., & Zhao, L. (2018). Field experience and performance analysis of floating PV technologies in the tropics. *Progress in Photovoltaics: Research and Applications*, *26*(12), 957-967.'
Bottom right: Amiot, B., Chiodetti, M., le Berre, R., Radouane, K., Boublil, D., Dupeyrat, P., Vermeyen, K., & Giroux-Julien, S. (2020). Floating photovoltaics - On-site measurements in temperate climate and lake influence on module behavior. *37th European Photovoltaic Solar Energy Conference and Exhibition*, 1772–1776.

Moisture ingress: ground-mounted versus floating PV

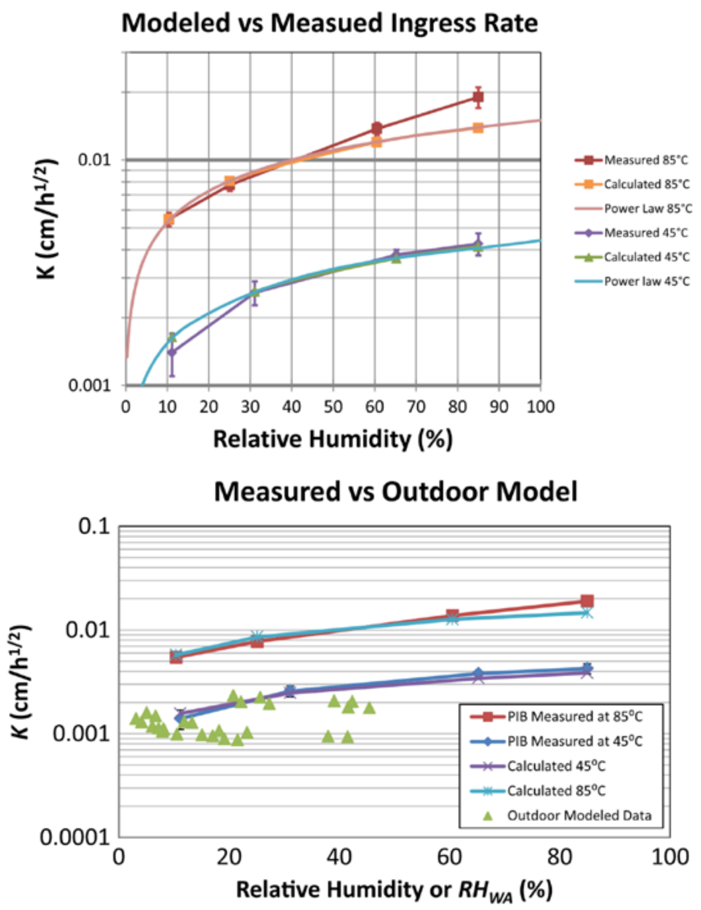
- Presence of liquid water:
  - General assumption that PV panel is impermeable to liquid water
  - Liquid water can be present inside module due to supersaturation or via delamination
  - *"Liquid water in a PV device is much more corrosive than dissolved water vapor because it facilitates diffusion of corrosion by-products increasing degradation rates" (Kempe et al., 2014)*
  - Not much published on immersion testing/modeling for PV, but could be relevant for (F)PV

- Presence of salt:
  - Can increase corrosion by facilitating ions at metallic surfaces
  - Shown to decrease adhesion strength between Si and encapsulant significantly (Dhere & Raravikar, 2001)
  - Associated to other issues, such as PID, as well
  - Again, not much published on the topic

Kempe, M. D., Dameron, A. A., & Reese, M. O. (2014). Evaluation of moisture ingress from the perimeter of photovoltaic modules. Progress in Photovoltaics: Research and Applications, 22(11), 1159–1171. https://doi.org/10.1002/pip.2374
Dhere, N. G., & Raravikar, N. R. (2001). Adhesional shear strength and surface analysis of a PV module deployed in harsh coastal climate. Solar Energy Materials and Solar Cells, 67(1-4), 363-367.

How to deal with moisture in PV modules

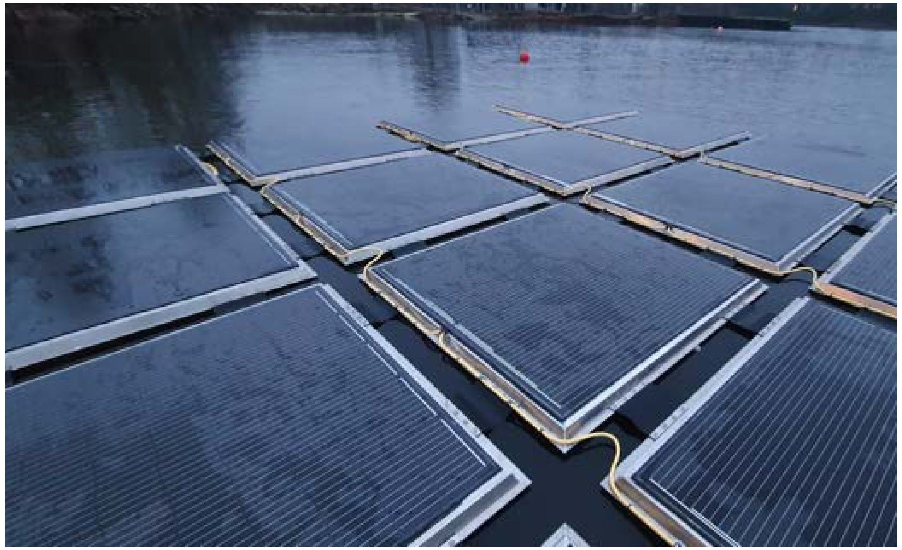
- Keep it out of the module → edge sealants
- Commonly used for thin-film PV
- (Desiccant filled) polyisobutylene (PIB) commonly used
  - Typical sealant height of ~0.5mm
  - Extensive modelling and experimental work evaluating such sealants

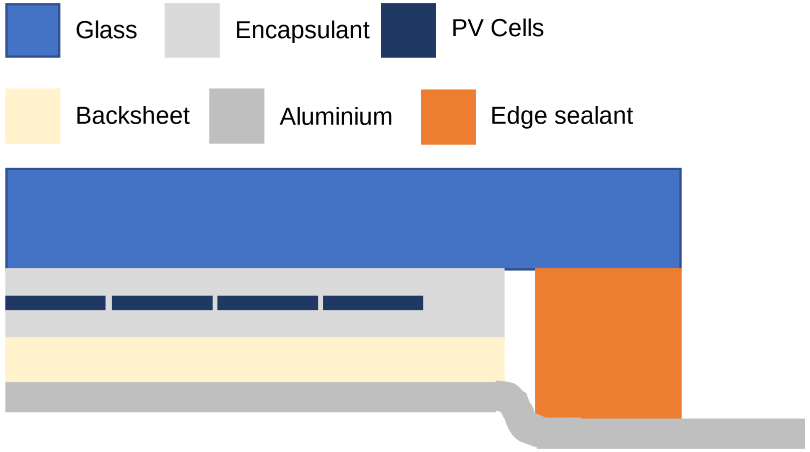


Kempe, M. D., Nobles, D. L., Postak, L., & Calderon, J. A. (2018). Moisture ingress prediction in polyisobutylene-based edge seal with molecular sieve desiccant. *Progress in Photovoltaics: Research and Applications*, *26*(2), 93-101.

Edge sealants for floating PV

- Integrated floating PV technology
  - PV module integrated with aluminium float, modules flat on water
- Required sealant height of roughly 1 cm, so commercially available sealants not suitable
- Two sealant materials evaluated
  - Hot melt butyl
  - Silicone
- Evaluation of moisture ingress through the sealant and adhesion with glass and aluminium
  - Shear pull testing shows no decrease in adhesion strength after 1000h damp heat or UV exposure
  - Focus on moisture ingress here





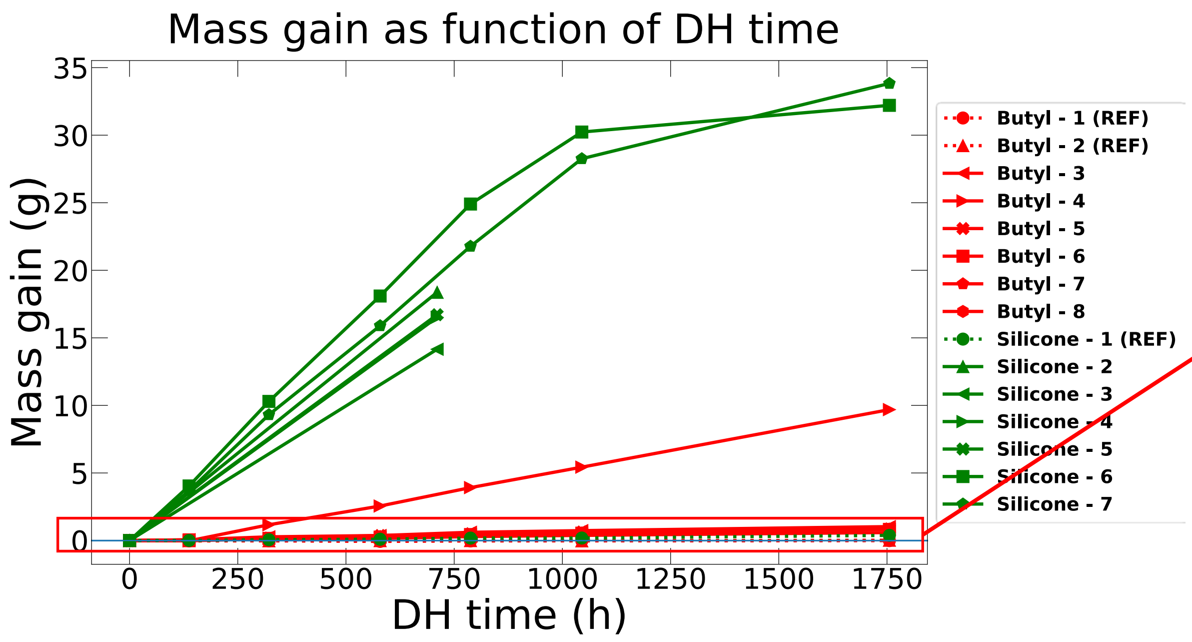
Evaluation of moisture ingress

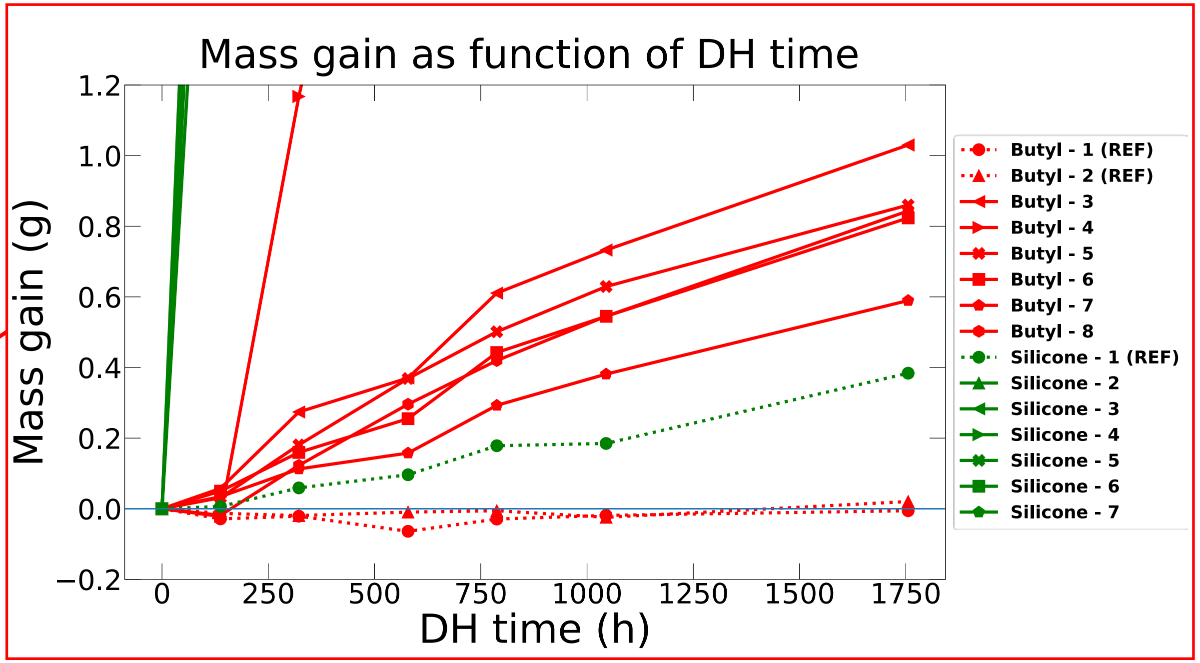
- Use of gravimetric method
  - Coupons exposed to damp heat (DH),
    - IEC 61215 MQT 13: 85 °C, 85% relative humidity
  - Or continuous immersion
    - IEC 60529: 1 meter depth, room temperature

  - Ingress measured by weighing samples before and after exposure
    - Measurement uncertainty of +/- 30 mg
    - High throughput of samples, allowing for decent statistics

- Results of 1755h of damp heat and immersion shown here

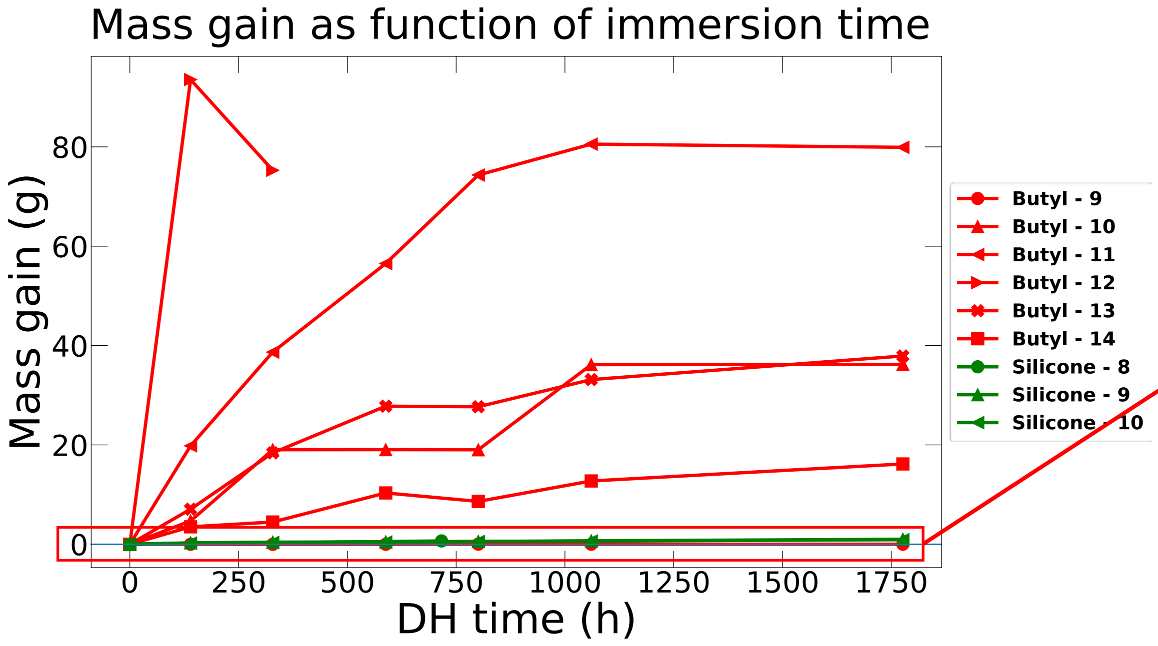
Results of damp heat

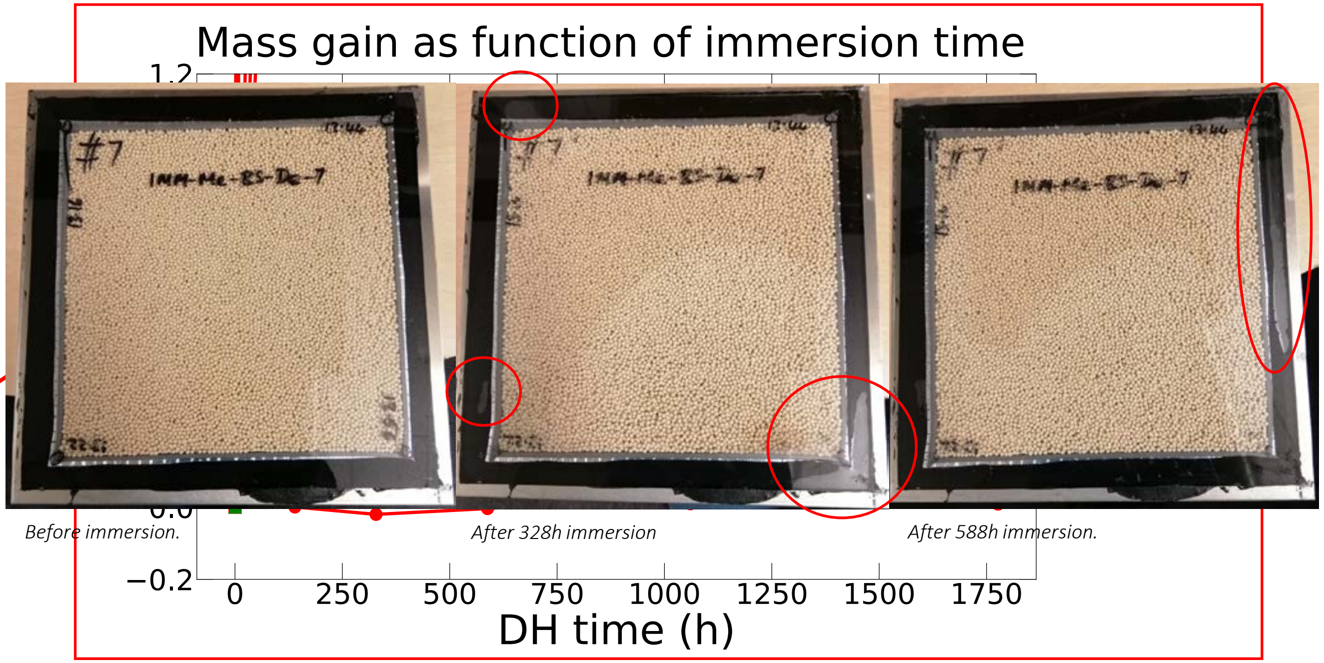




- Silicone samples with relatively high ingress in DH
- Butyl samples low ingress (0.6 – 1 g), except for one sample
  - Expected pinhole in sealant during fabrication, but not observed directly
- No delamination observed in any of the samples

Results of immersion





- Butyl samples failing: delamination of sealant at glass interface
- Silicone samples holding up well

Experiment conclusions

- Butyl low ingress in presence of water vapor, silicone in presence of liquid water
- Double sealant of butyl on the inside and silicone on outside potential to minimize both types of moisture ingress
- Prototypes with this double sealant have been deployed

Field experiments

- Prototype of 8 modules, all using a double sealant
  - 4 deployed in February 2022, 4 more in March 2022

- Regular field characterization, consisting of:
  - Visual inspection
    - No defects observed so far
  - IV measurements
    - Measured parameters output close to nameplate values
  - Insulation testing
    - No signs of leakage currents

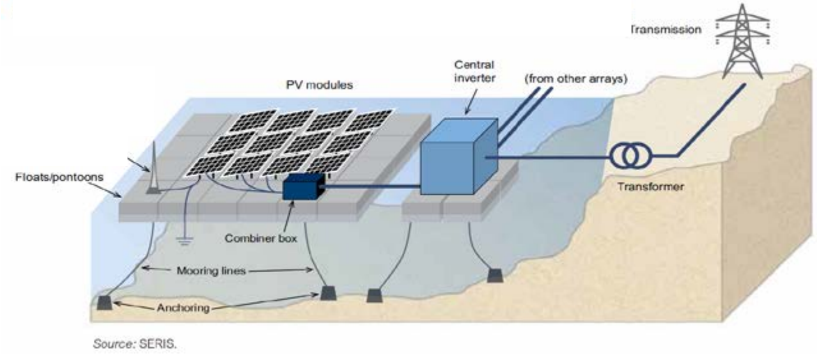
➢ No signs of moisture ingress (or other defects)

Future work

- Experimental evaluation of double sealant
  - Follow-up damp heat and immersion experiment
- Continued field characterization
  - Addition of IR imaging
  - Upcoming pilots
- Updated results to be presented at WCPEC-8

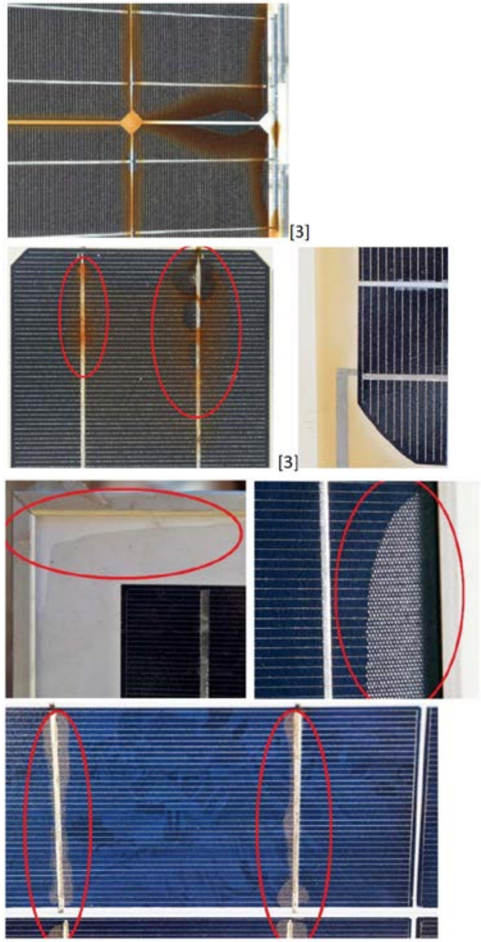
Conclusions

- Solar panels on water → great!



Where sun meets water, World bank, 2019

- Water in solar panels→ not great!



Sinclair, K., & Sinclair, M. (2016). *Silicon Solar Module Visual Inspection Guide: Catalogue of Defects to be used as a Screening Tool.* www.zayedenergyecologycentre.org

- Edge sealants have the potential to extend the lifetime of FPV modules

Thank you for your attention!

Thanks to Josefine Selj, Torunn Kjeldstad and Gaute Otnes for contributions to the presentation

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