

PV: From concept to large scale industry

Technology trends and opportunities for Norwegian companies

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Smart Energy Network – November 28th 2019

«Death inspires me like a dog inspires a rabbit»

-TØP



Research Center for Sustainable Solar Cell Technology

(«FME SuSolTech»: 2017 – 2025 ~ 250 MNOK)



NORGES BONDELAG



Norges miljø- og
biovitenskapelige
universitet



Institute for Energy Technology



Agenda

- The PV industry in 2019
- Technology trends in PV
 - High efficiency, silicon-based PV
 - Utility-scale PV
 - Smart building
 - Building Integrated PV (BIPV)
 - Floating PV (f-PV)
- Resulting challenges from the success of PV (= more opportunities)

Main messages

- PV is growing ridiculously fast
- PV industry = industry
- ~~Revolution~~
- We must participate
- Dogma is hard to fight
- Solar is ready to deliver

Huge commercial opportunities

No free lunches

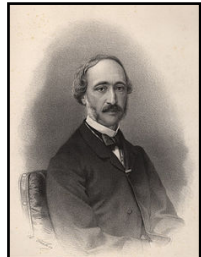
Evolution

Innovation from «outside» hard

«Home market», «neutrality»...

Are we ready to accept?

A brief history of PV



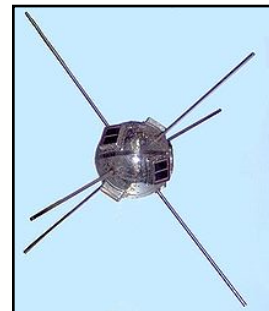
BEQUEREL
1839

The current, if not wanted immediately, can be either stored where produced, in storage batteries, ... or transmitted a distance and there used

FRITTS
1883



BELL LABS
1954



VANGUARD 1
1958

«OIL CRISIS»
1973 - 1986

SCANWAFER
1996

1 GW_p
2002

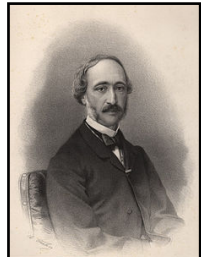
10 GW_p
2008

100 GW_p
2012

500 GW_p
2018

1825 1850 1875 1900 1925 1950 1975 2000 2025

A brief history of PV



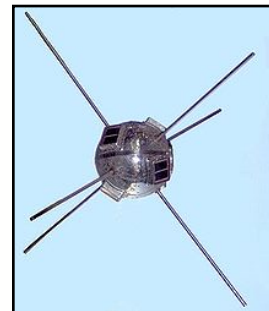
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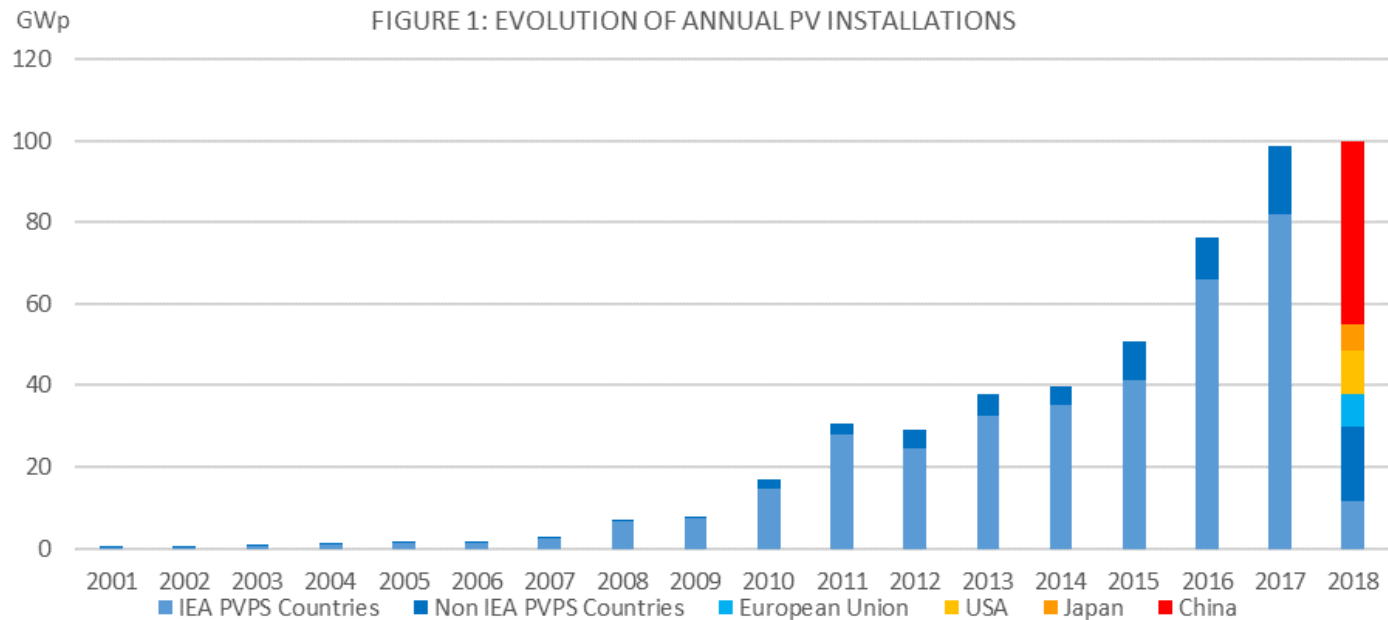
500 GW_p
2018

1825 1850 1875 1900 1925 1950 1975 2000 2025

VISION AND SCIENTIFIC FUNDAMENT

EARLY INDUSTRIALIZATION

INDUSTRY



Kilde: IEA-PVPS 2019

Solar PV grew faster than any other fuel in 2016, opening a new era for solar power

4 October 2017



new solar PV capacity around the world grew by 50%, reaching over 74 gigawatts (Photograph: Shutterstock)

Explore findings from Renewables 2017

New solar PV capacity grew by 50% last year, with China accounting for almost half of the global expansion, according to the International Energy Agency's latest renewables market analysis and forecast. For the first time, solar PV additions rose faster than any other fuel, surpassing the net growth in coal.

Boosted by a strong solar PV market, renewables accounted for almost two-thirds of net new power capacity around the world last year, with almost 165 gigawatts (GW) coming online, according to the new report, *Renewables 2017*. Renewables will continue to have a strong growth in coming years. By 2022, renewable electricity capacity should

about 1,000 GW by 2022, which equals about half of the current global capacity in coal and gas," said Dr Fath Birol, the executive director of the IEA. "What we are witnessing is the start of a new era in which we expect that solar PV capacity growth will be higher than any other renewable



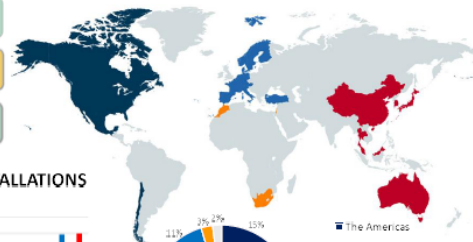
Source: IEA-PVPS 2018/Scatec Solar/IEA 2019

A Snapshot of Global PV Markets - 2019

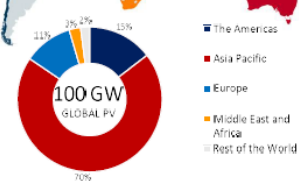
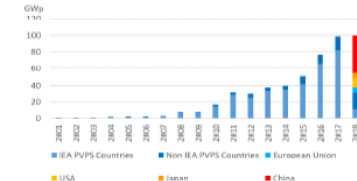
THE LATEST SURVEY RESULTS ON PV MARKETS AND POLICIES FROM THE IEA PVPS PROGRAMME IN 2018

By Gaëtan Masson (IEA PVPS, Belgium), José Domenech (UNEF, Spain), Flurin Hösler (E.ON Energy, Switzerland), Izumi Katsuzaka (JETS Corporation, Japan), Dr. Johann Lindthal (Solarenergie-Service, Germany), Francesca Tili (GSE, Italy)

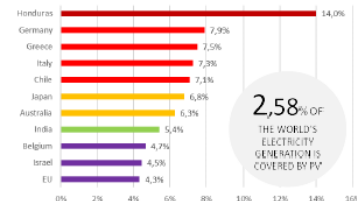
TOP PV MARKETS 2018



EVOLUTION OF ANNUAL PV INSTALLATIONS



COUNTRIES WITH HIGHEST PV PENETRATION



2,58% OF
THE WORLD'S
ELECTRICITY
GENERATION IS
COVERED BY PV

SOLAR PV PER CAPITA 2018 Watt/capita



100 GW were installed all over the world by the end of 2018

China is the world's #1 PV market

32 countries had at least 1 GW of cumulative PV capacity at the end of 2018

10 countries installed at least 1 GW each in 2018



298 Mt
CO₂ emissions
avoided in 2018

100 GW_p

- ~400 million solar panels
- ~500 000 tons of SUPER-clean silicon
- ~25 billion wafers turned into ~25 billion solar cells



NorSun

Technology trends



Best Research-Cell Efficiencies

Cell Efficiency (%)

52

48

44

40

36

32

28

24

20

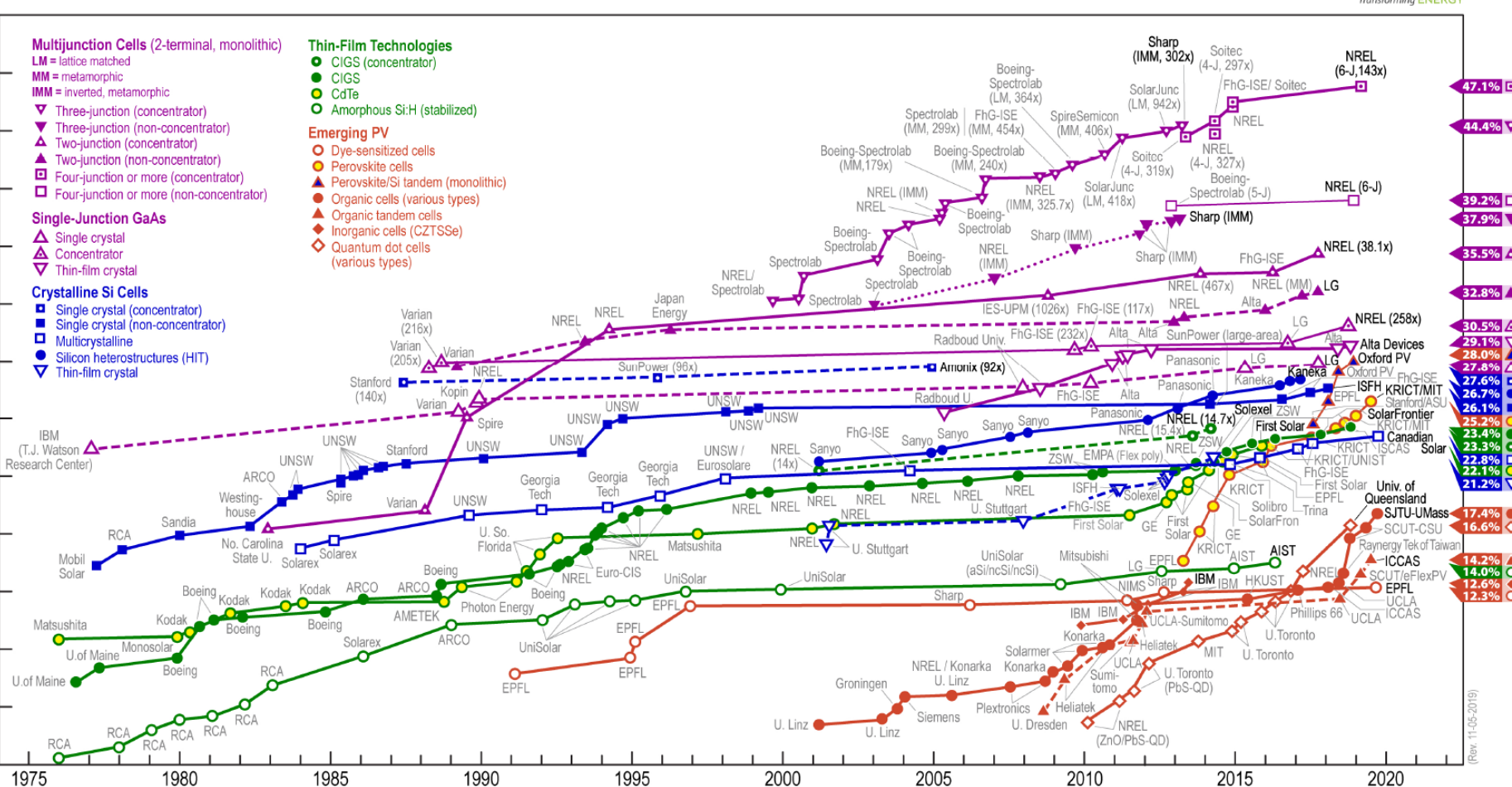
16

12

8

4

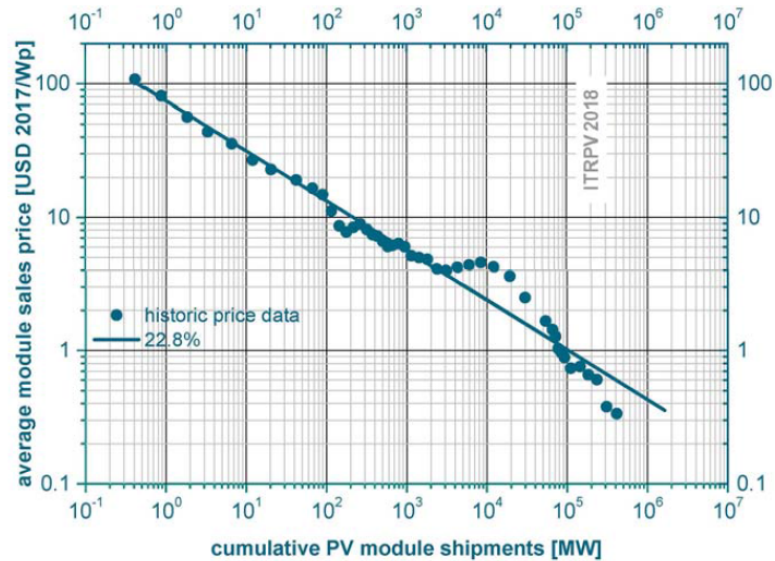
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(Rev. 11-05-2019)

How to win...

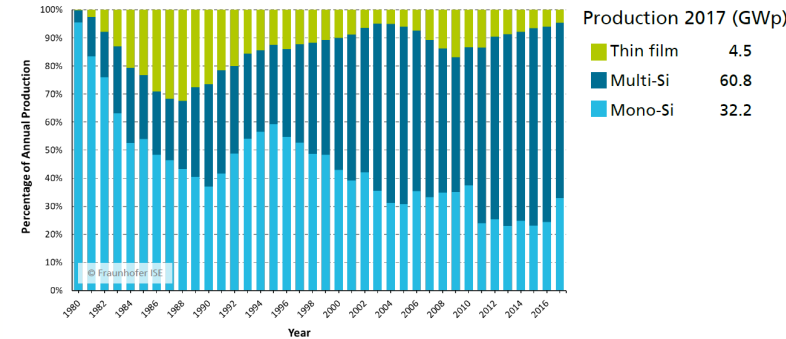
Learning curve for module price as a function of cumulative shipments



High efficiency, silicon-based PV

- Crystalline silicon completely dominates
- Introduction of high efficiency architectures
 - PERC, HJT, IBC, bifacial
- Efficient cells require high quality materials
 - Norwegian opportunity: we KNOW silicon
- The silicon tandem heavily investigated
 - Large efficiency boost available

PV Production by Technology Percentage of Global Annual Production

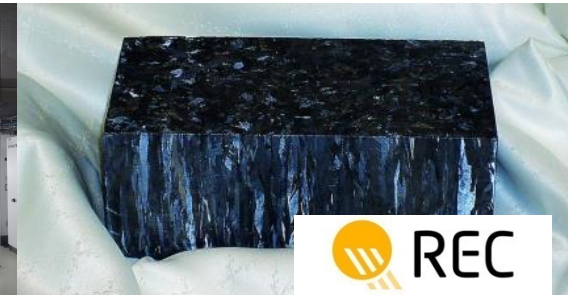


Data: from 2000 to 2010: Navigant; from 2011: IHS (Mono-/Multi- proportion from cell production). Graph: PSE GmbH 2018

21

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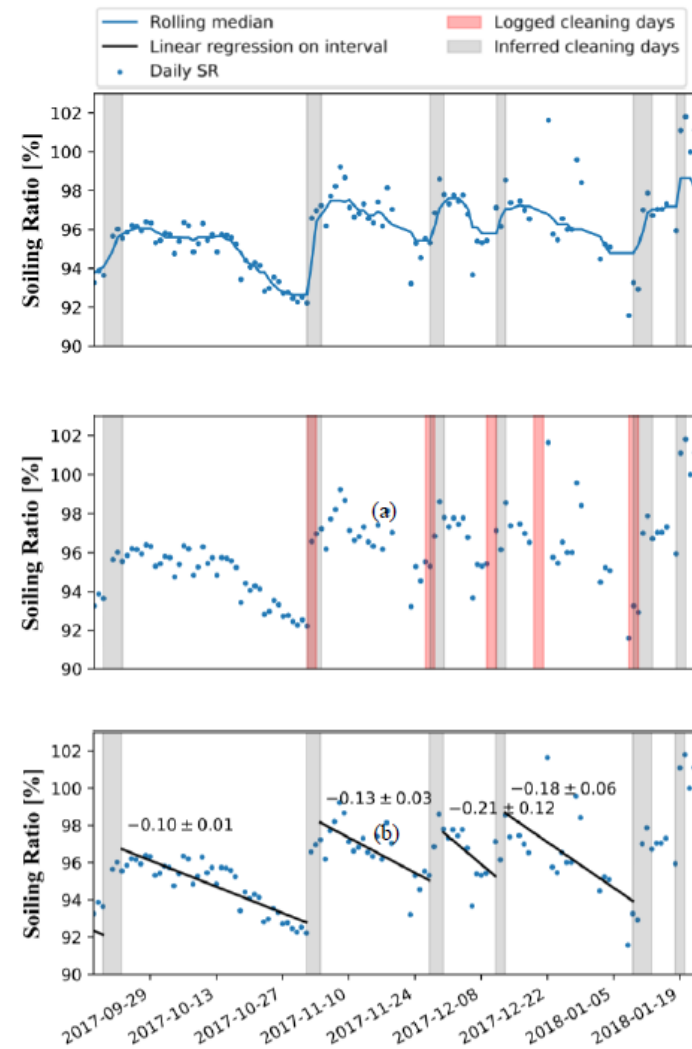


Sustainable silicon production

- Si materials, ingots and wafers produced by factories IN Norway by 2018 were core constituents of a total PV capacity of 6.4 GW_p
- Every year, these produce more than 6 TWh
- This results in a global, annual reduction of electricity production-related emissions in excess of 6 Mtons CO₂!
- **Norwegian speciality: sustainable silicon production!**

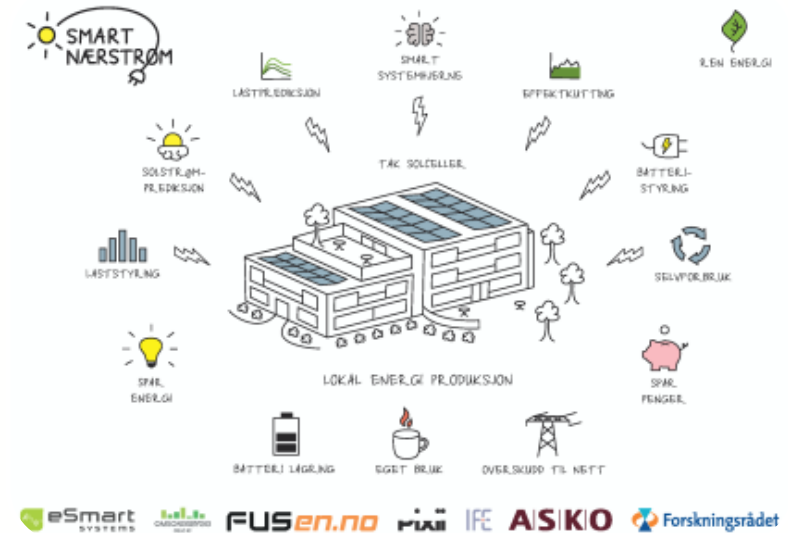
Utility-scale PV

- Very large numbers of components
- Increasing complexity
 - Energy storage and/or conditioning
 - Hybridization
- Introduction of data-driven O&M
 - Performance and degradation analysis
 - Big data
 - Imaging technologies
 - Drone inspections
- Very exciting time in the PV industry
 - We learn NOW!



Smart buildings

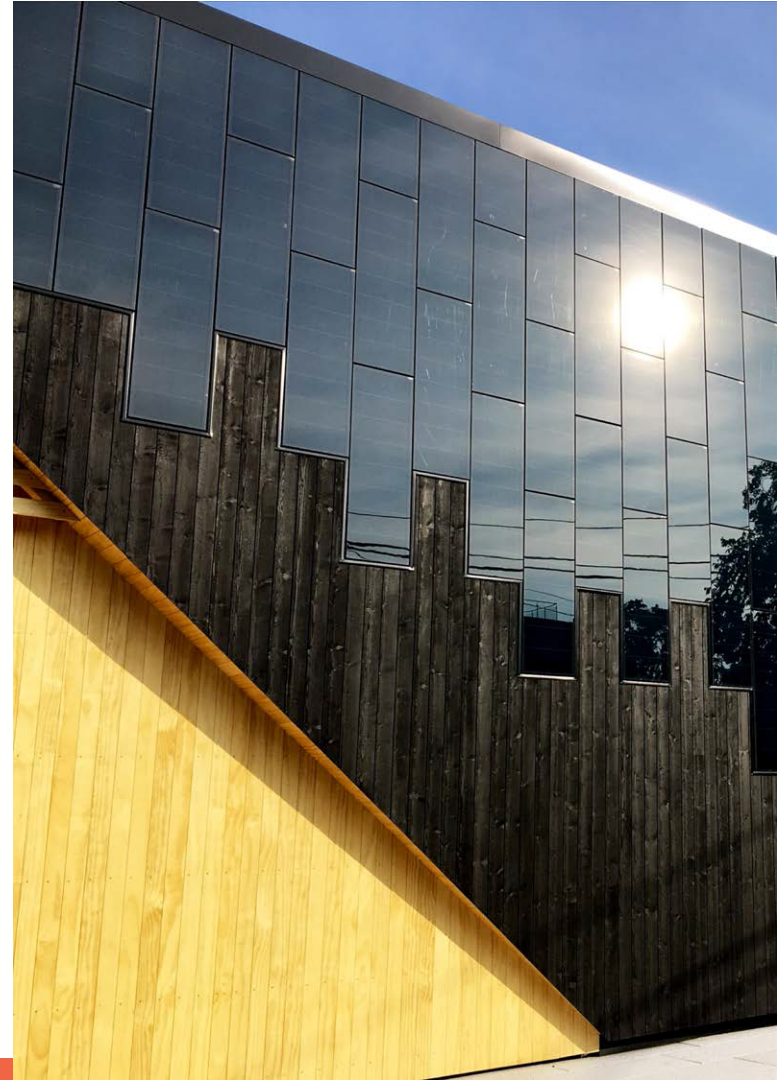
- Solar is a gateway to smartness...
- «Smartness»: digitalization
 - Monitoring systems
 - Metering, reporting, visualization
 - Logging, filtering and analytics
 - Fault detection and diagnostics (FDD)
 - Forecasting (production, load, grid prices)
 - Demand side management
 - Energy storage (which leads to even more «smartness»)



Building-integrated PV (BIPV)

- Potentially very large benefits
 - Substitution
 - Synergies during installation
 - Record low installation costs feasible
 - Record low environmental footprint within reach
- Norway among the leading countries
 - Bold building standards
 - Competent installers

Source: FUSen



Floating PV (f-PV)

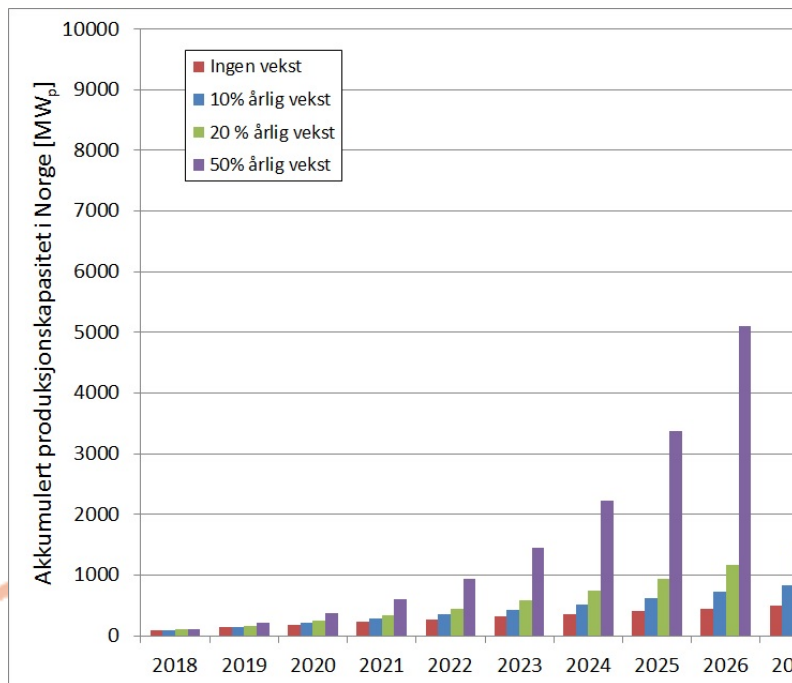
- New, rapidly growing segment
- Combines PV and maritime competence
 - Excellent fit for Norway!
 - Can we exploit this fact?
- Several potentially important advantages
 - Land use
 - «Cooling effect» = higher production
 - Low cost



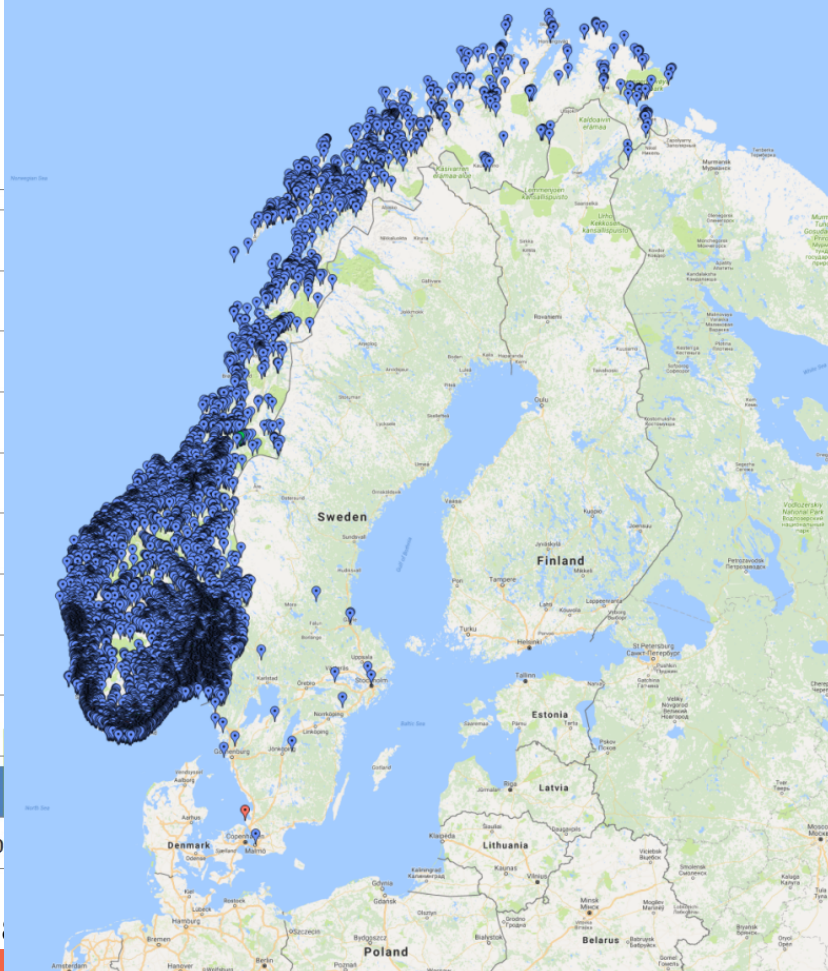
Related challenges



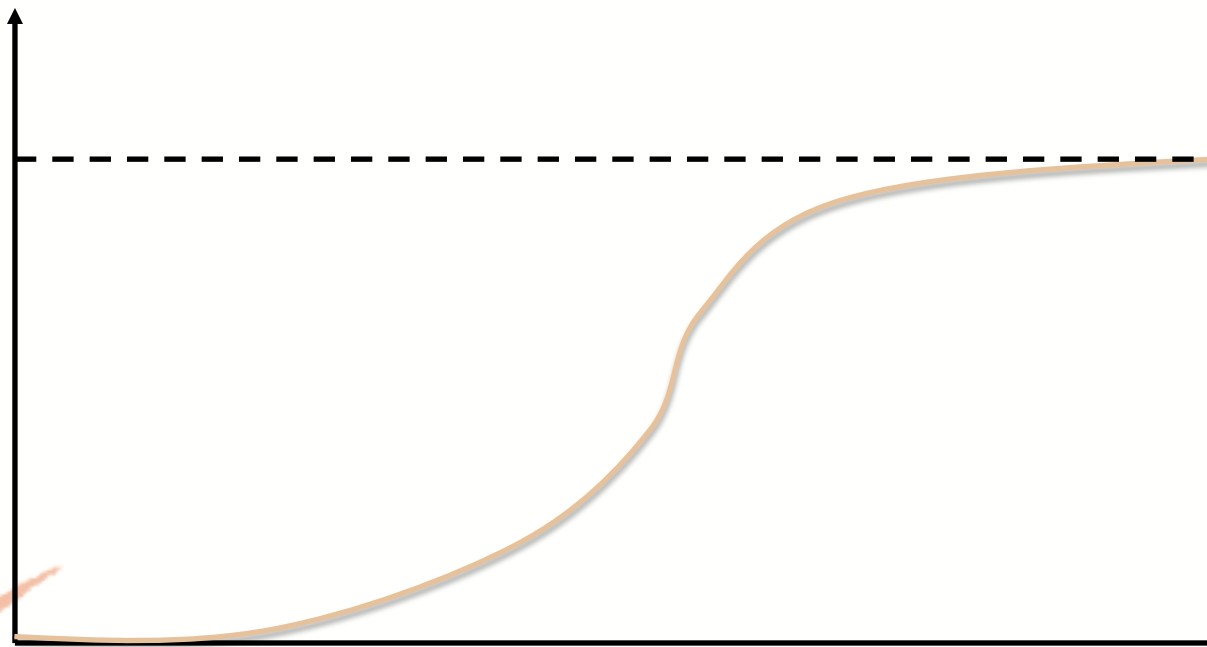
Eternal exponential growth is fun,



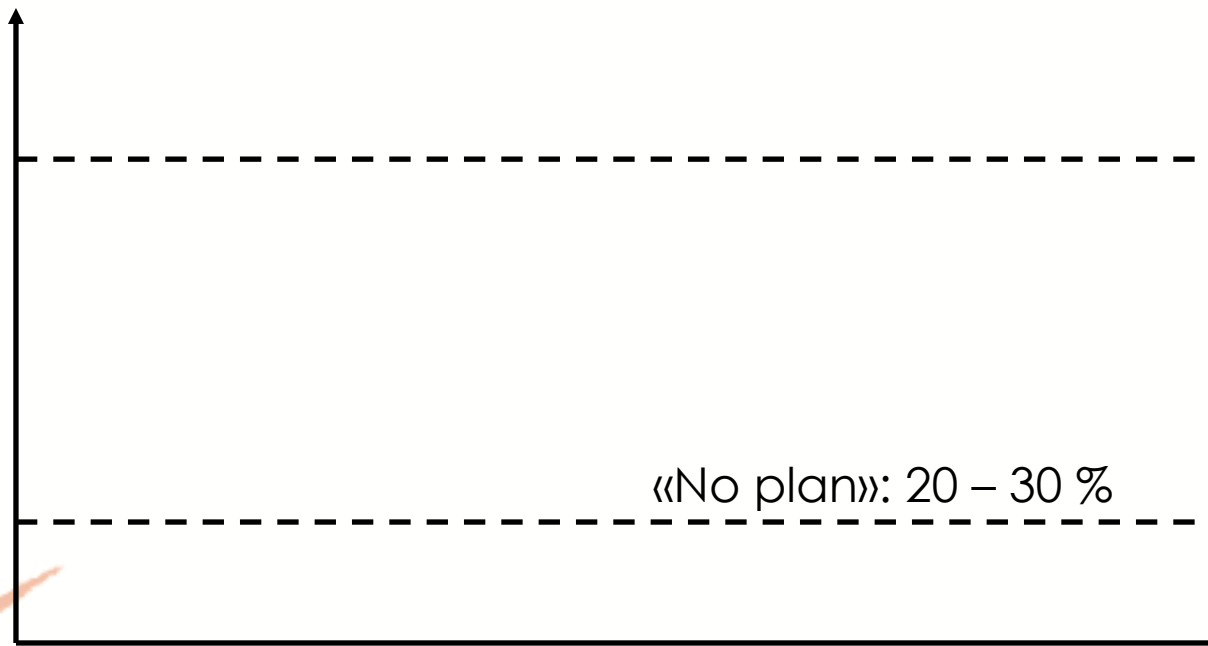
Kilde: Marstein (NTVA) 2018



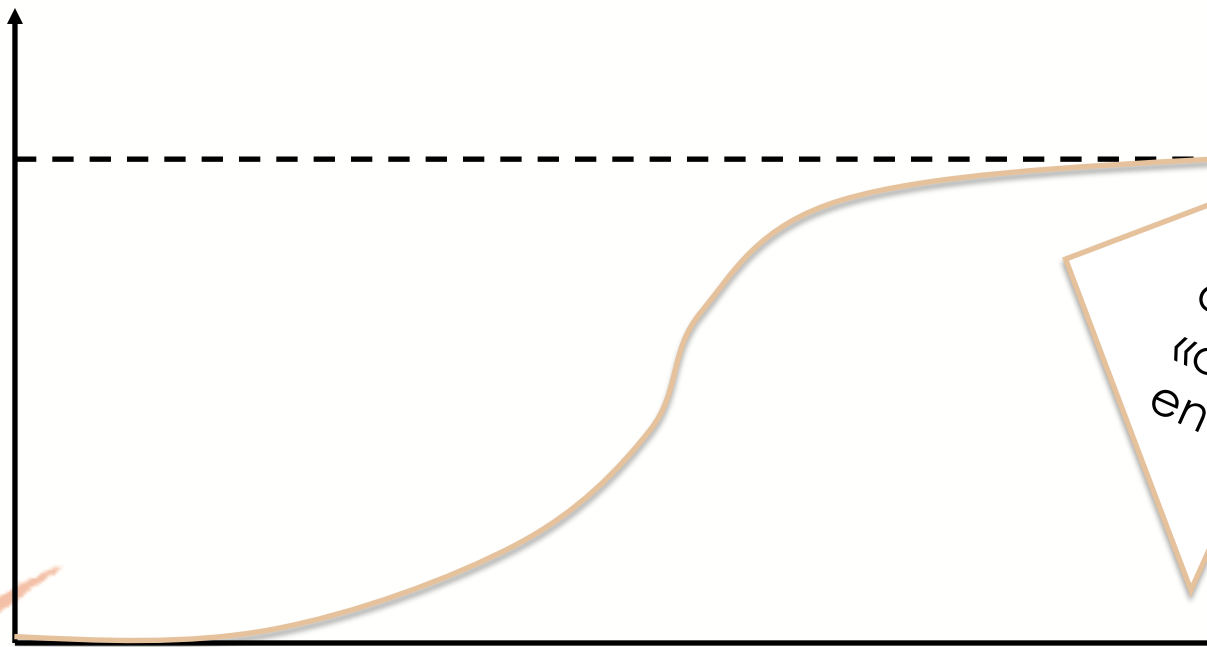
Plausible development



Tresholds

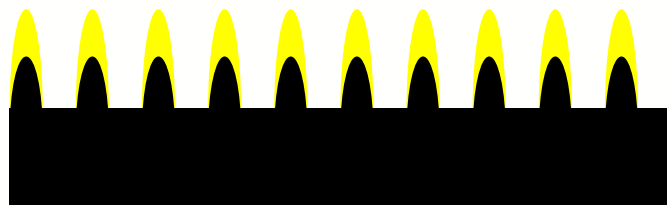


Tresholds

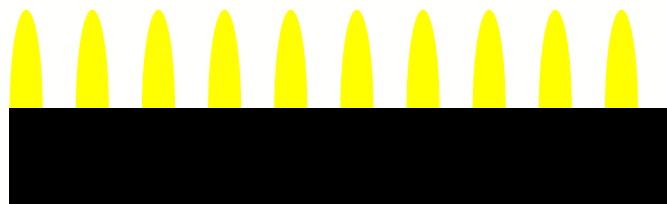


ENORMOUS
opportunity for
«compatible»
energy systems

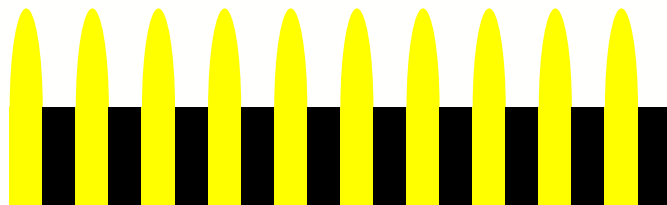
Who will fix this?



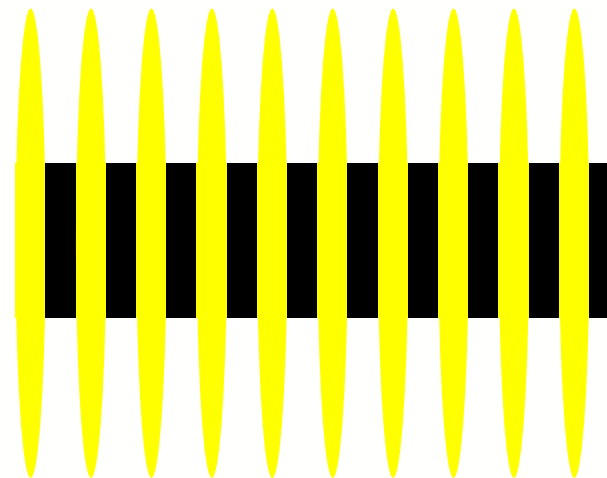
Yesterday



Today



Tomorrow



End game

Concluding remarks

- Discovering a megatrend is not enough
 - We must supply competitive solutions for a real, future market!
- We have a PV industry
 - A very good starting point for an even larger PV industry!
- Everybody wants to win (incl. China)
 - We need optimism, not naivety!
- Much room for (evolutionary) innovation in the PV industry still!
 - Many good, new and old ideas to be implemented!
- PV is highly addictive...

Thank you for your attention!





The Norwegian Research Centre for Sustainable Solar Cell Technology