# THE FUTURE OF ENERGY STORAGE

***Storage, conversion and circular economy helping eachother***

Mark Bolech, TNO

# THE FUTURE OF ENERGY STORAGE

Dr. M. Bolech

TNO innovation for life

Use button ‘Pictures’  to change background
Text-only start sheets can be added using ‘New slide/Nieuwe dia’

# OUTLINE OF PRESENTATION

- Brief introduction of speaker
- brief introduction  of TNO

- Climate change is becoming more and more visible
- Energy transition most important in limiting climate impact
- Huge storage capacity needed in sustainable  energy system
- Storage and conversion options  (present and foreseeable future)
- Conclusion

# INTRODUCTION

- Short intro on who I am and what I do
- Short introduction of TNO (Netherlands Organisation for applied Scientific Research)
- Number of employees: 2,600
- Purpose: Applied science
- Motto: Innovation for life
- Founded: 1932 (by law)




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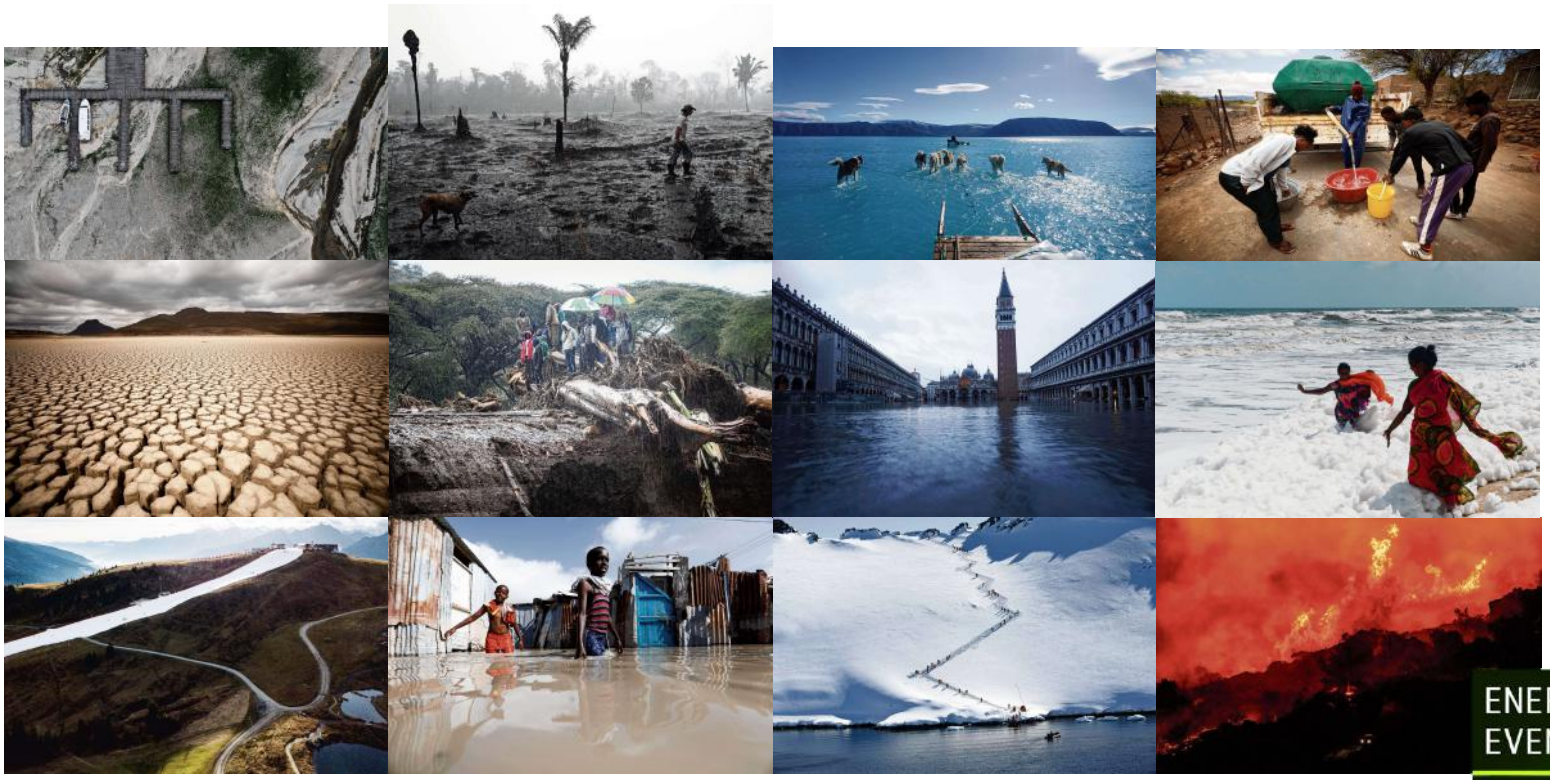
# TIME FOR ACTION



Source: NRC Handelsblad 01-12-2019



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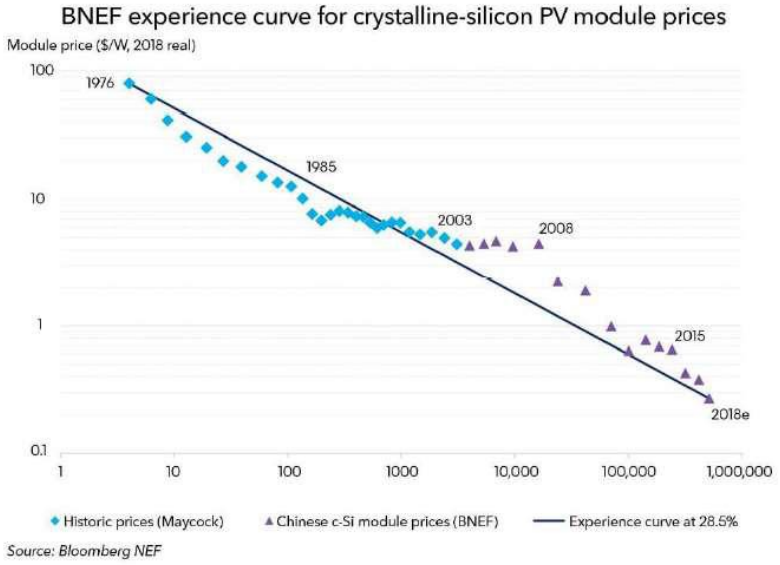
# DEVELOPMENTS IN ENERGY SYSTEM

- **Bloomberg NEF:** “three technology dynamics are reshaping the energy systems:”

1. PV modules show a 28.5 % learning rate over the last 40 years
2. Larger, more efficient wind turbines to significantly reduce the costs of on shore and off-shore wind power
3. Enormous numbers of electric vehicles to stabilize the power system of the future



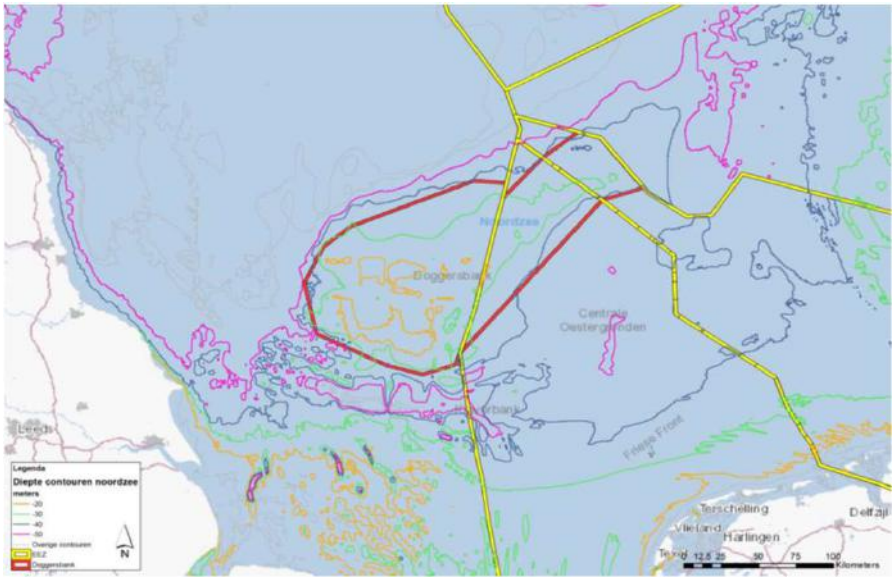
# EUROPEAN ENERGY TRANSITION

- **Ambitious goals**:
- EU ambition: 80-95% $CO_2$ reduction in 2050 compared with 1990 levels
  - Large volumes of RES needed.
  - **2 TW** of sun PV required to cover **50%** of the electricity demand (TU Delft)
  - **600 GW** offshore & onshore wind power required to cover **50%** of the electricity demand (WindEurope)

- What to do about imbalance day-night and worse summer-winter?

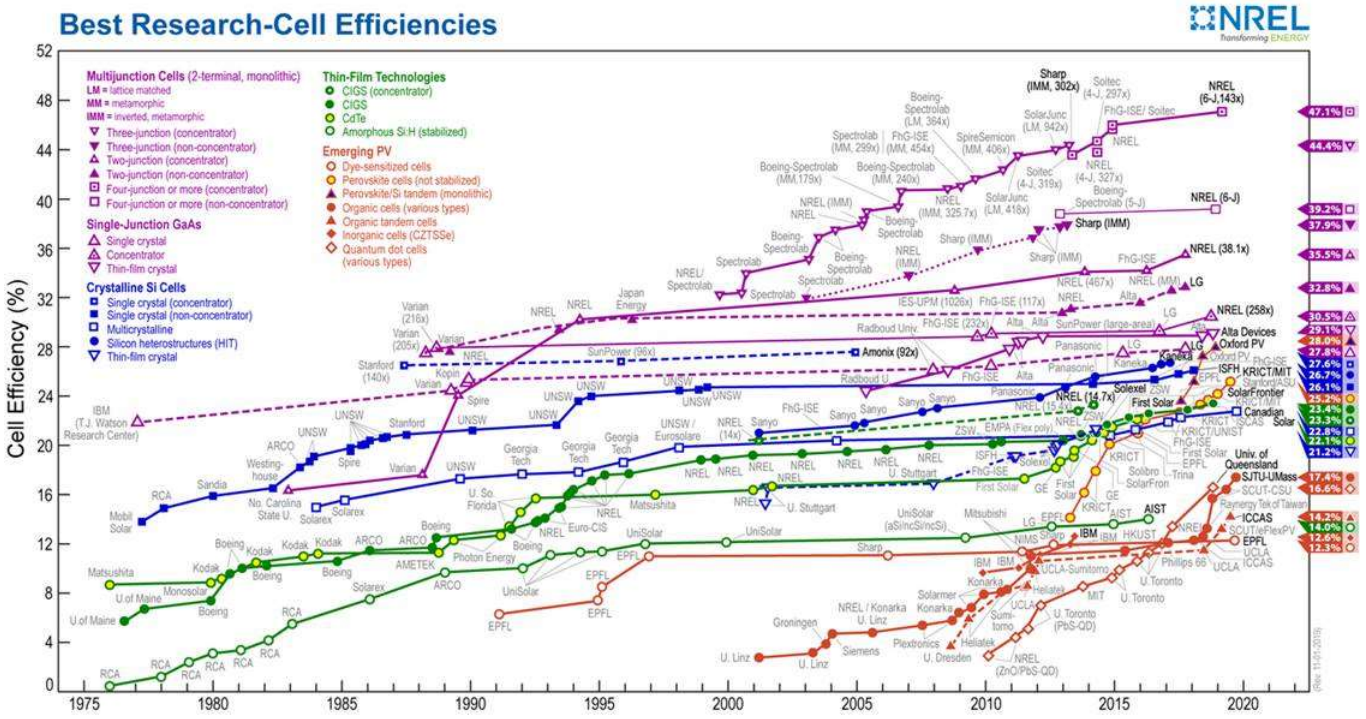
# WIND ENERGY

- When far shore becomes necessary to realize the required scale
- **Shallow waters**
- Water depth has a significant impact on the development for offshore wind. A development in shallow waters contributes significantly to cost reduction.
- Wind conditions out there are such that wind turbines on Doggerbank are economically attractive.




Source: TenneT view future offshore grid (2016)

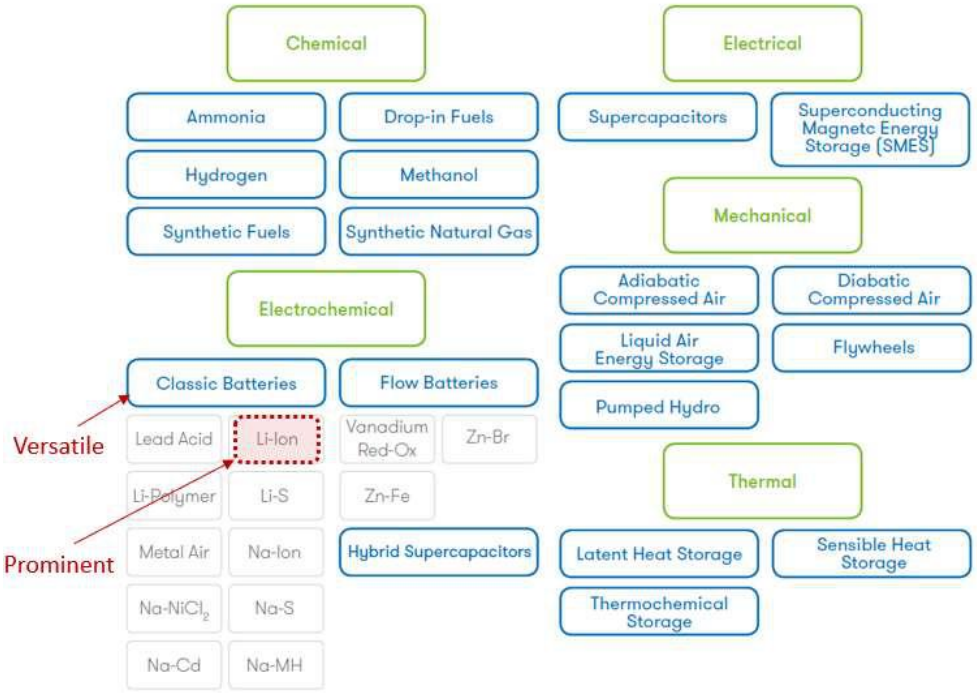
# DEVELOPMENTS IN PHOTOVOLTAICS




This plot is courtesy of the National Renewable Energy Laboratory, Golde

- **Efficient technology**
  η = 20% commercially,
- **Low cost**
  4-6 cts /kWh average
- **Industrially mature**
- > 500 GW installed
  40% growth / a
- >60% centralized
- **Loss in performance**
  <1%/year (> 20 years)
- Recycling

# ENERGY STORAGE TECHNOLOGIES



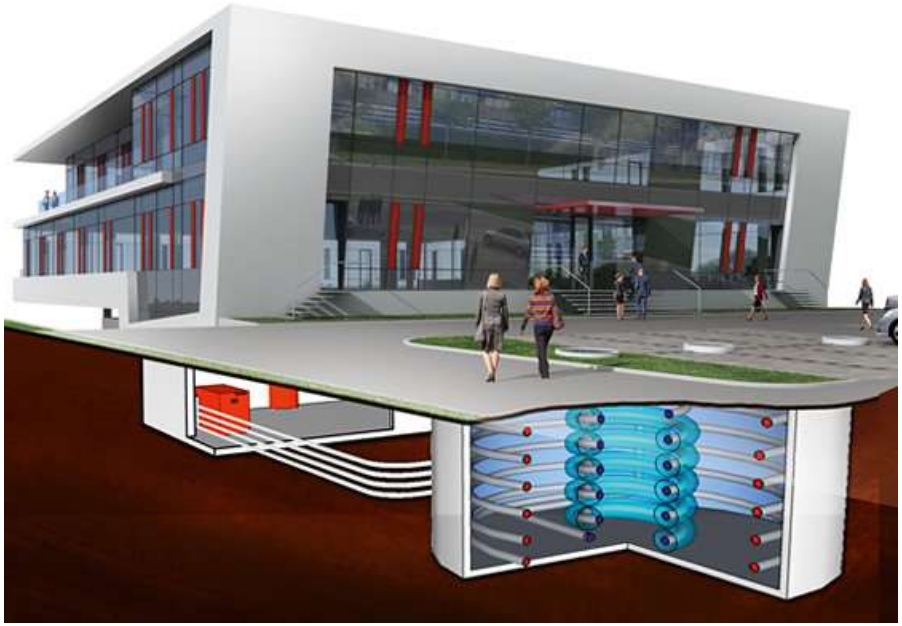

Source: http://ease-storage.eu/energy-storage/technologies/

**Example Criteria of choice:**

- Form & amount of energy
- Location of source
- Safety of storage
- Portable/Stationary uses
- Size/Weight limitations
- Storage duration desired
- Response time needed
- Cost of ownership
- Round trip efficiency of storage

# HEATING &COOLING

- Electric heat pumps working on surface (in dutch TEO & TEA) or subsurface **wate**r are very attractive in NL: "limitless" supply AND a very high Coefficient of Performance.
- Heat-pump revolution in industrial heating and cooling is around the corner
- Seasonal storage of large quantities of heat (and cold!) possible in ATES or artificial reservoirs.
- Deep geothermal energy may be an attractive option in some locations as well.



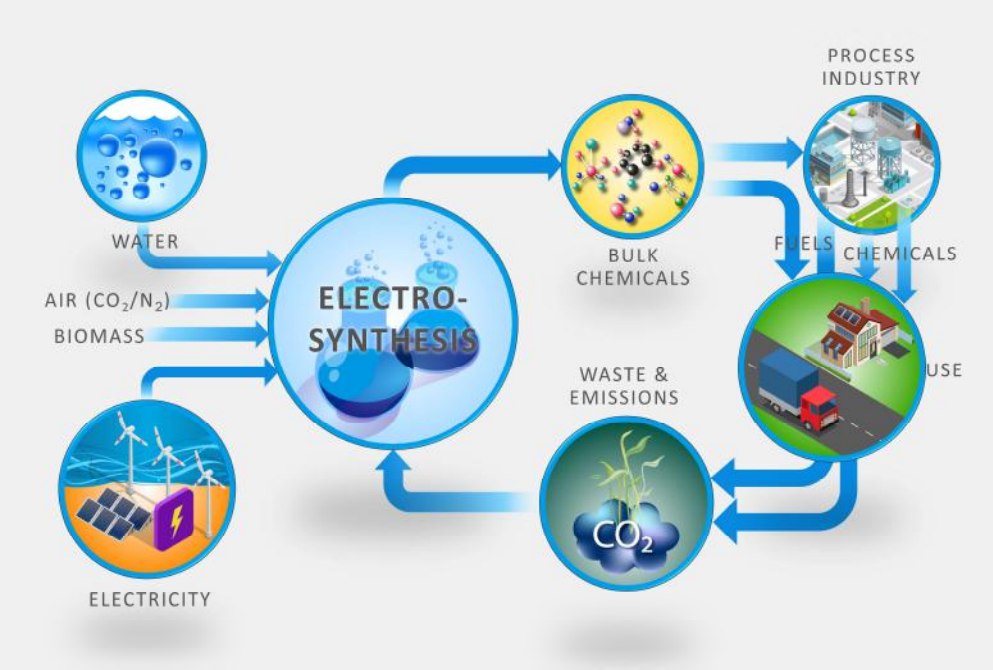
Office building realised in Nagold (D)
- Heat pump: 85 kW heating / 65 kW cooling
- Summer: solar collectors → 350 $m^3$ water reservoir
- Winter: cooling water buffer → ice

# POWER TO X

- Making molecules from “left over” sustainable energy (NL is lagging behind badly)

- Feedstock for the manufacturing / polymer industry of tomorrow
- Sustainable synthetic (drop-in) alternatives for fossil based fuels
- Green hydrogen instead of grey hydrogen (SMR) for all sorts of chemical processes (70 Mtons / a)
- Sustainable gases to be transported in our natural gas network
- Gaseous energy carriers can be stored in exhausted gas-fields

# CIRCULAR INDUSTRY




Source: TU Delft, e-refinery (2019)



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# $H_2$ AS AN ENERGY CARRIER

- Electric round trip efficiency: **34** % (DC → electrolysis of $H_2O$ → transport of $H_2$ → fuel cell making DC)
- Energy density (10.05 $MJ \cdot Nm^{-3}$ for H2 versus 31.7 $MJ \cdot Nm^{-3}$ for Slochteren natural gas)

- Making sustainable $H_2$ is much preferable to curtailment, though.

- Situation is even worse if want to carry $H_2$ around: need to *compress* ($\eta_{rt}$ ↓**28** %) or *liquify* ($\eta_{rt}$ ↓**20** %)
- John Bockris: “Hydrogen Economy to a Methanol Economy”
- Liquid hydrogen derivatives like methanol, formic acid, metal hydrides or $LiBH_4$

# LIGHTWEIGHT OPTION?

- $H_2$ will certainly be very important for future industry and society. Today 70 million tons annually!!
- Hydrogen fuel cell can also be an energy carrier for mobility.
- However, it presents ***at present*** no solution for heavy batteries


# STORAGE OF ELECTRIC ENERGY

***Wearable devices***

*(For smart-watches, smart-cards, smart textiles...)*

***Portable devices***

*(For personal electronics, portable device…)*

***Power tools***

*(For electric power tools, portable machines…)*

***Electric Vehicles***

*(For EVs, AGVs, electric scooter, drones...)*

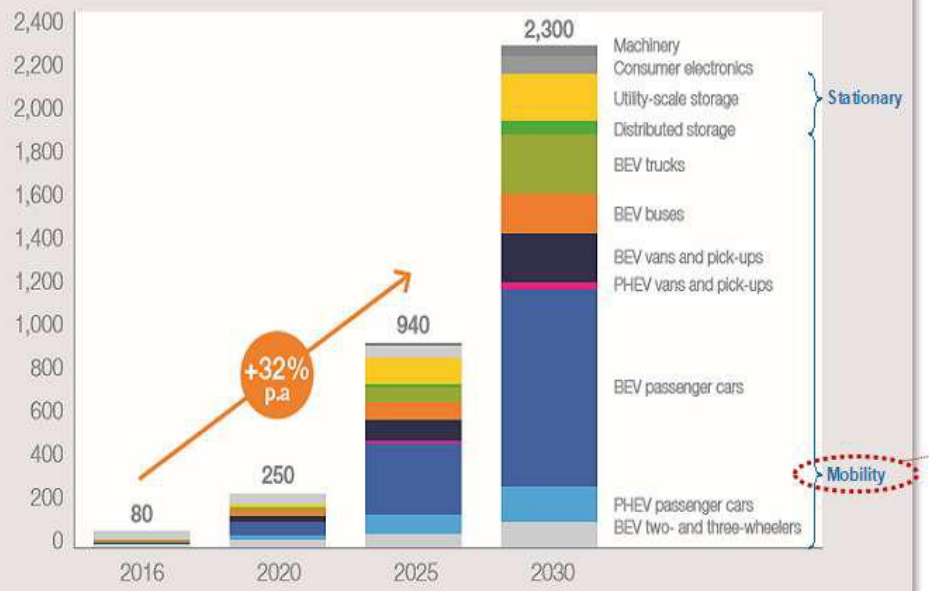
***Energy storage***

*(For renewable energy storage, grid back-up, ...)*

*mWh* — *Wh* — *kWh* — *MWh*

# BATTERY MARKET GROWTH: AUTOMOTIVE DRIVEN

Exhibit 1
Annual battery demand: electric mobility segments, stationary battery storage, consumer electronics, and machinery
GWh/yr




Source: McKinsey Energy Insights' Global Energy Perspective (March 2018), Avicenne

Battery developments are focussed mainly here

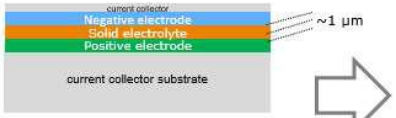
# BATTERIES

- Li-ion technology is already quite powerful and enabled the ZE mobility revolution that is developing


- Still better performance of batteries would be nice though (e.g. capacity, safety, charging speed)
- Two big steps are being chased in battery technology:
  1. Metal-air batteries (actually fuel cells)
  2. Solid state batteries

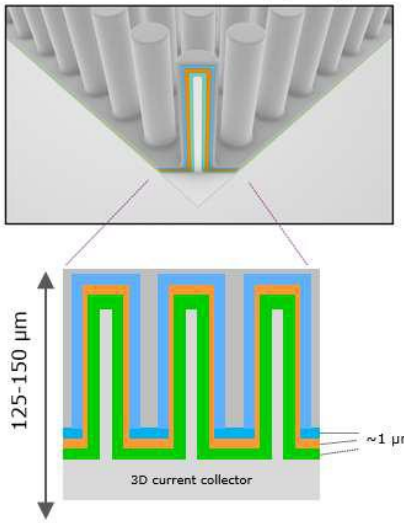
# THE SOLUTION: 3D SOLID-STATE BATTERY

**Planar Thin Film Li-ion batteries**




**High charging speed**

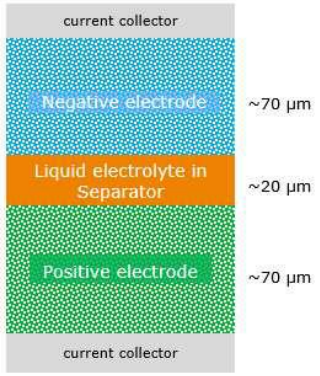
**3D Solid State Battery (3DB)**




**High energy density and Fast charging**

≈

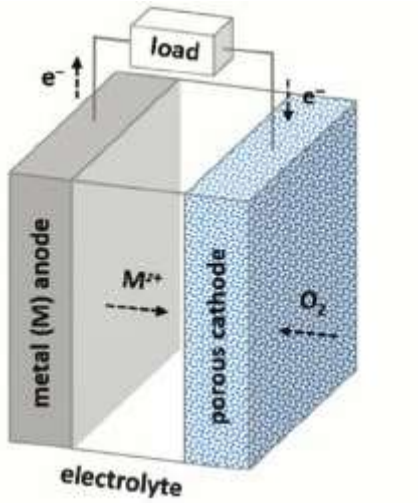
**Wet Li-ion batteries**




**High energy density**

# METAL-AIR BATTERIES

- Actually a fuel cell, with a metal as fuel
- Round trip efficiency ≈ 45 - 90 %  ($H_2$ ≈ **28** %)
- Effective specific energy:  Mg, Ti or Al may reach 8-10 MJ·kg$^{-1}$  (best present Li-ion ≈ 0.95 MJ·kg$^{-1}$)
- Stability and rechargeability…




Source: Min-Sik Park *et al.* Phys.Chem.Chem.Phys., **46** (2015)

# ZERO EMISSION AVIATION

- Relatively simple forms of unmanned or smallish airplanes now
- For example present model high altitude pseudo-satellite on the right. However, that holds a world endurance record: uninterrupted flight for 26 days!
- Great potential though if solid state batteries and (particularly) metal air batteries become available.

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# ZERO EMISSION AVIATION

The future of energy storage

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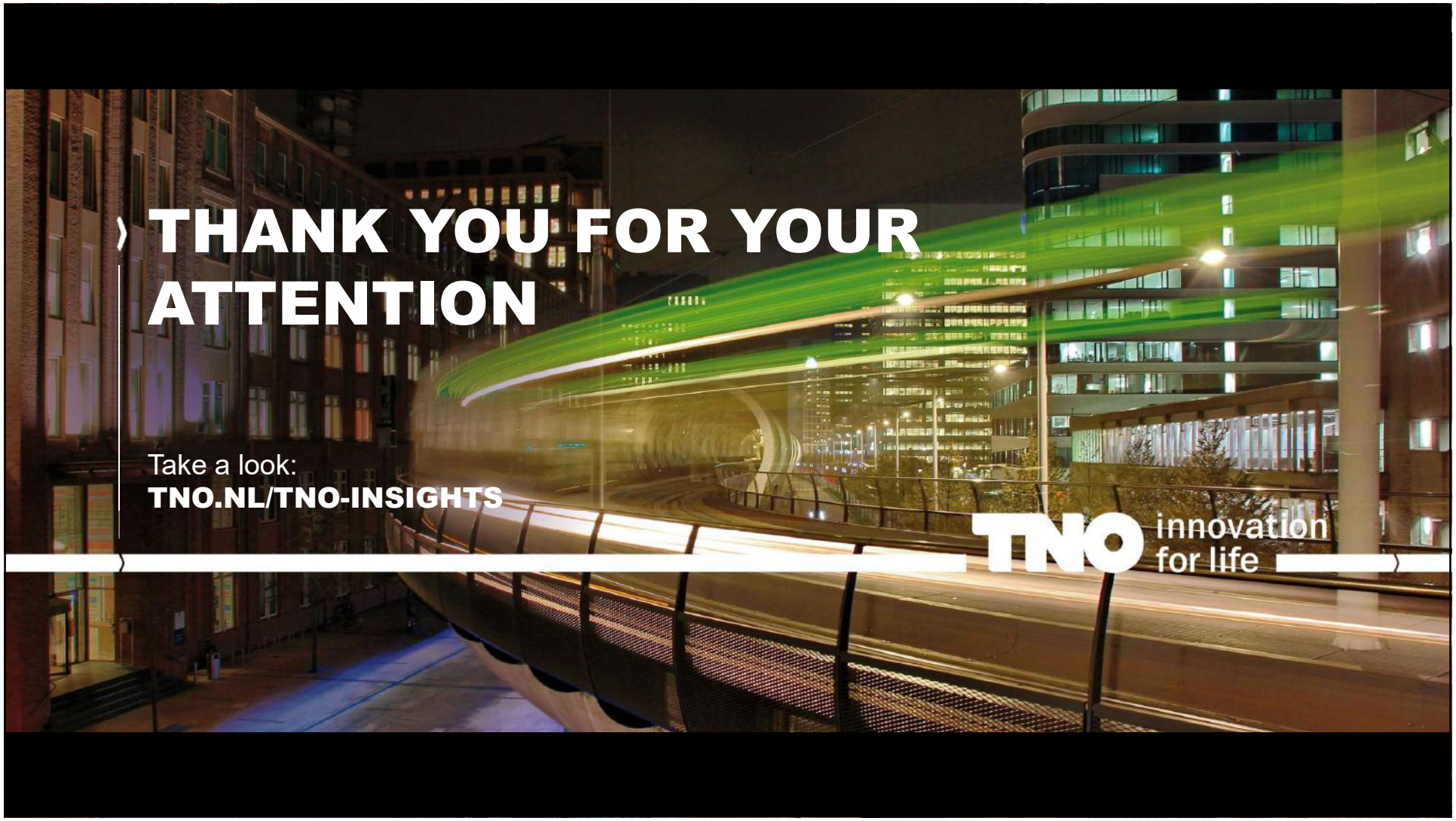
# CONCLUSION

- Time for action in NL

- Sustainable energy system based on wind and solar (most probably at present) needs storage
  - Huge opportunities for heat and cold storage
  - Large possibilities for storage in battery electric vehicles and planes
  - Better batteries and fuel cells are welcome
  - Conversion of energy into molecules delivers future feedstock and or energy carriers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Open for questions and discussion