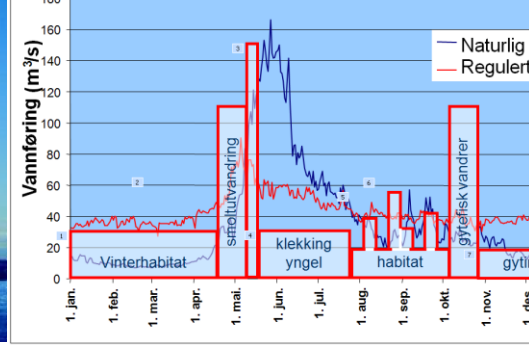







# Mechanical energy storage with focus on hydropower – status and future development

SINTEF

NTNU
100 skapende år

NINA

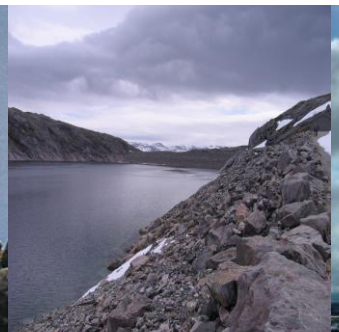
NATURHISTORISK MUSEUM
UNIVERSITETET I OSLO

NIVA

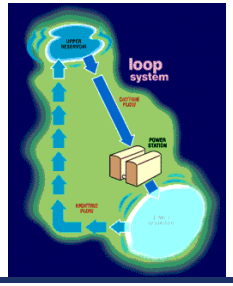
uni Research


***Atle Harby, SINTEF Energy Research and***
***Centre for environmental design of renewable energy - CEDREN***

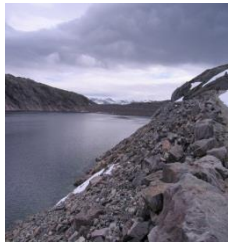


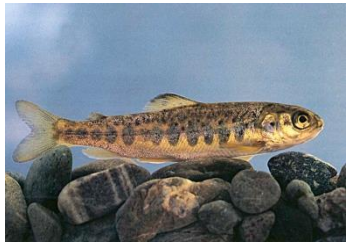



Hydropower technology




Environmental impacts of hydropower

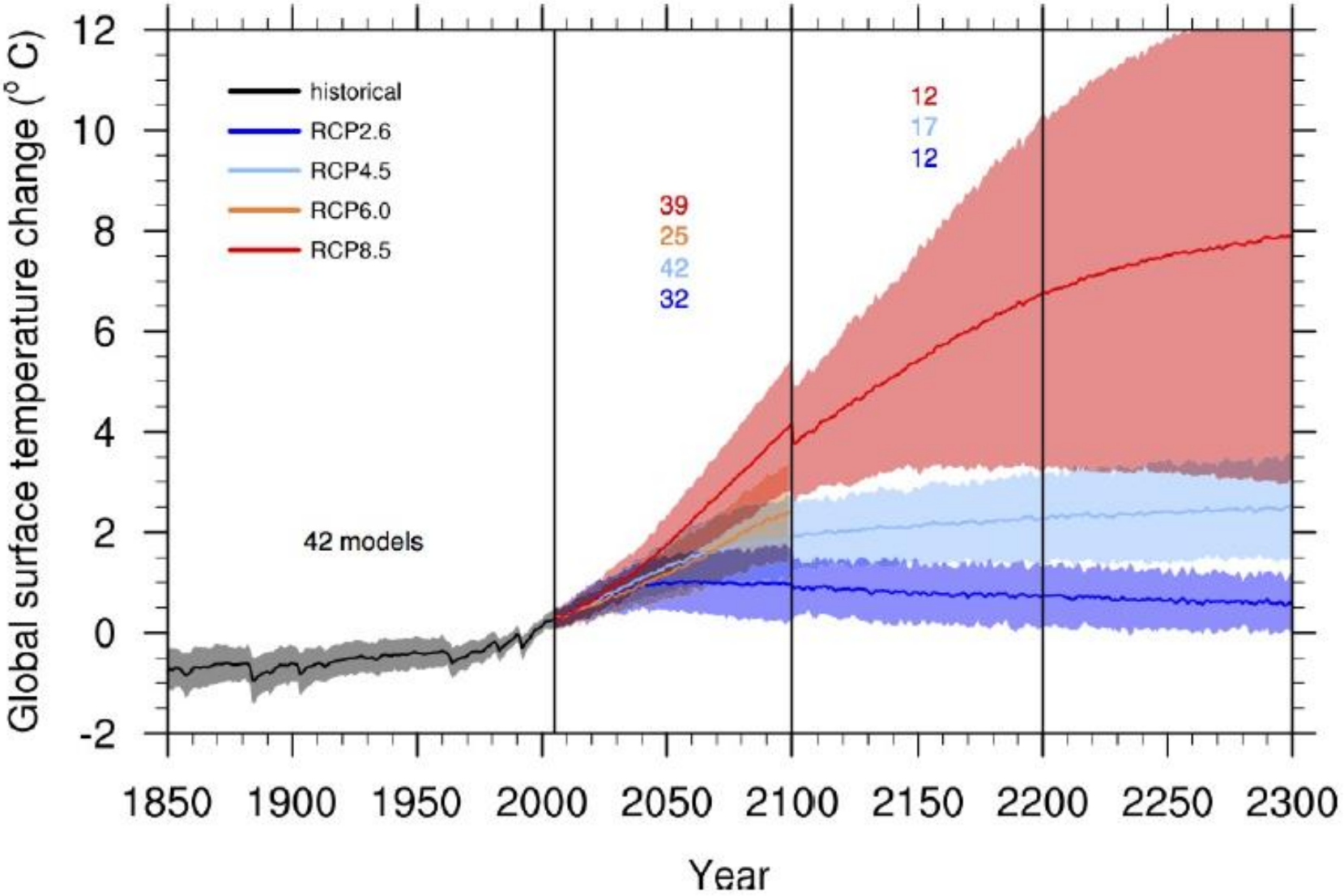




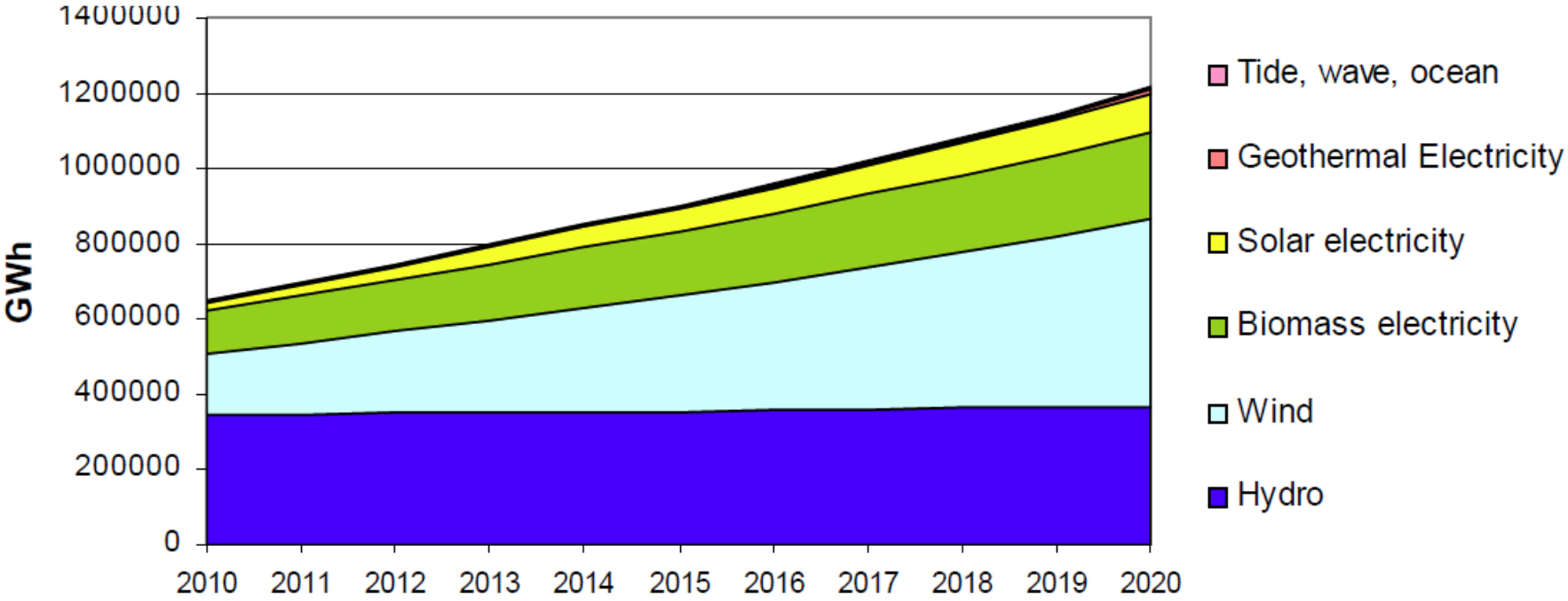
Environmental impacts of wind power and power transmisson

How to reconcile energy and environment policy?


# The Background – Climate Change



# Towards 2020 – Implementation of the RES-directive

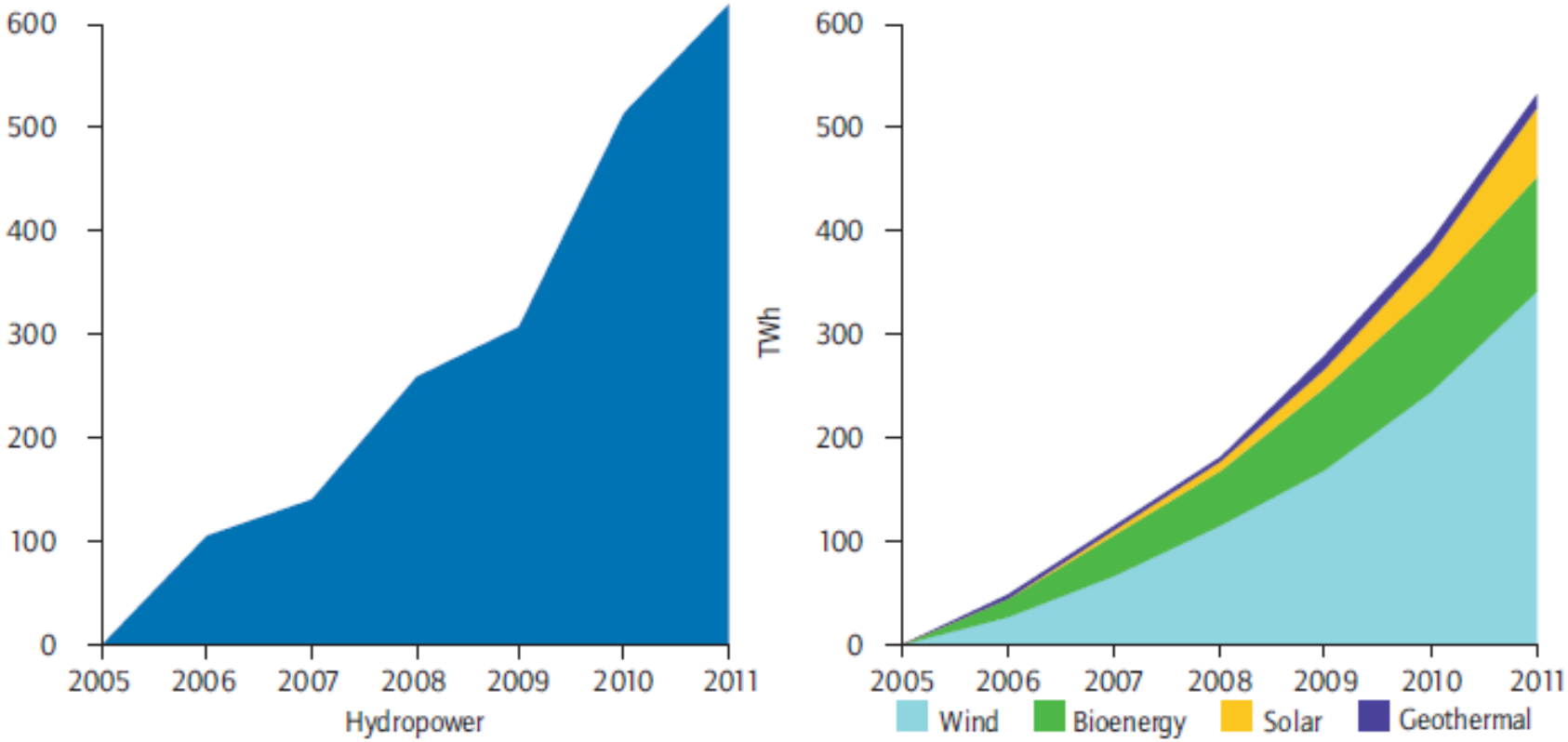



RES generation from **632** TWh in 2010 to **1152** TWh in 2020
Largest increase in Wind - ca 120 GW and 305 TWh
Also rapid increase in Solar PV - ca 65 GW og 100 TWh

➔ Increase of non-dispatchable power generation (wind, solar PV)

# A surprising fact found in IEA Roadmap cont.

Figure 3: Electricity generation from recent additions to hydropower (left) and other renewables (right)



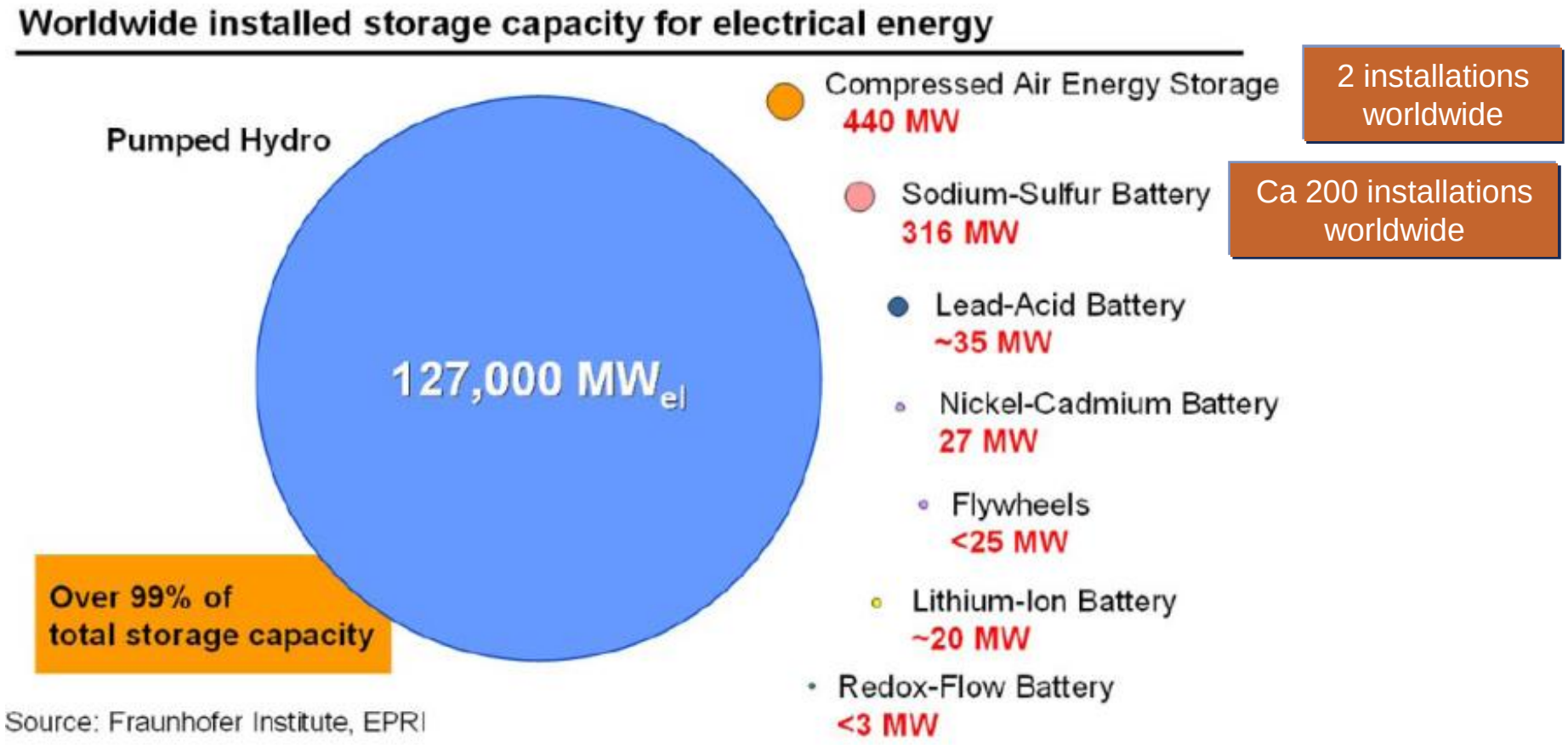

Source: IEA, 2012b.

# Energy scenarios


- Transmission and distribution infrastructure
- Energy storage technologies
- Demand side management
- Improved forecasting of resource availability

Maybe as much as 340 TWh of storage volume and 150 GW of balancing capacity needed in Europe by 2050

# Installed Energy Storage capacity




*Worldwide installed rated power of storage facilities for **electrical energy**. Such power level can be sustained for up to several hours or shorter*

# Mechanical storage

## Hydro

- Operates typically on weeks to hours
- Many applications for both energy and storage
- World-wide potential

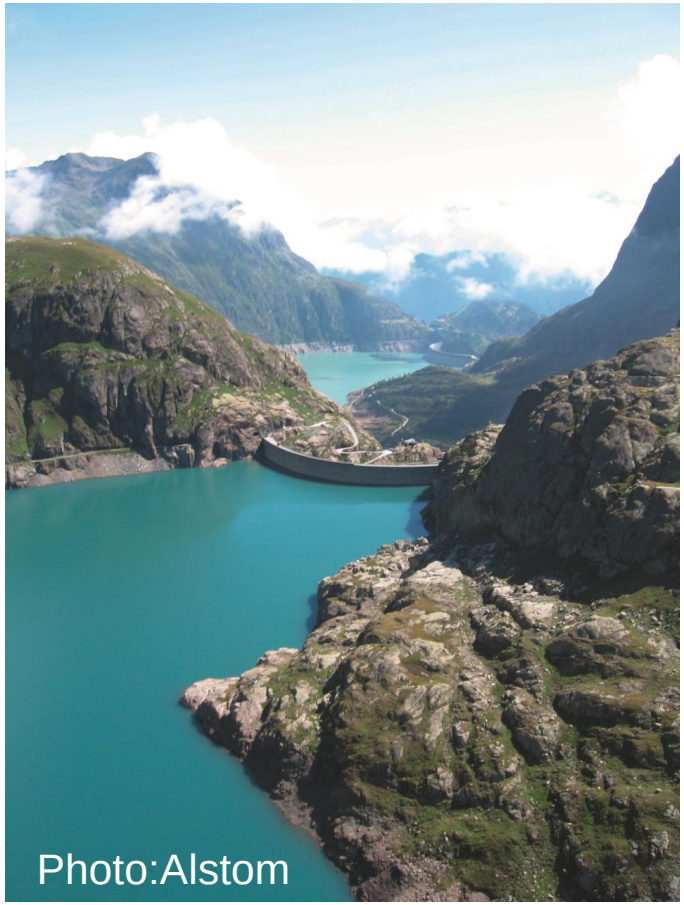
## Compressed air

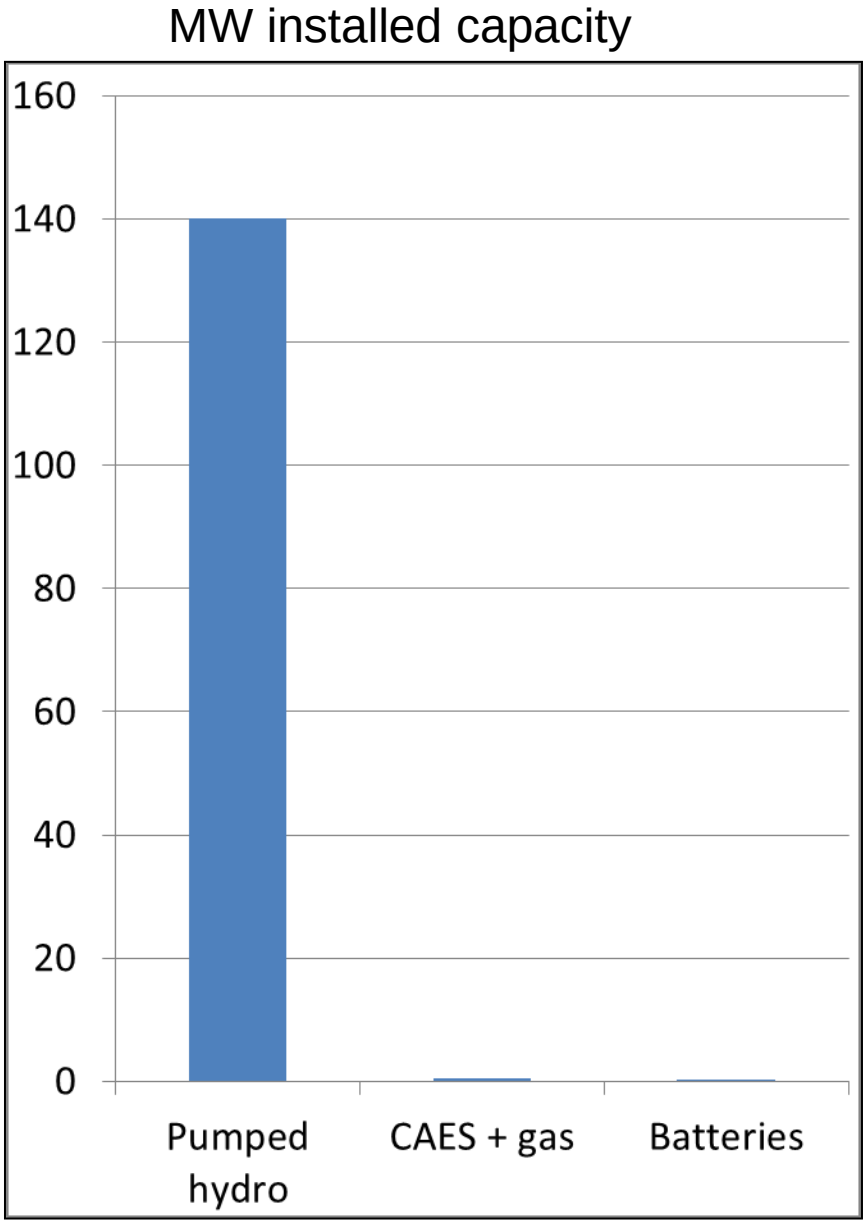
- Operates typically on hours
- Two commercial energy storage plants
- Need for more research

## Flywheels

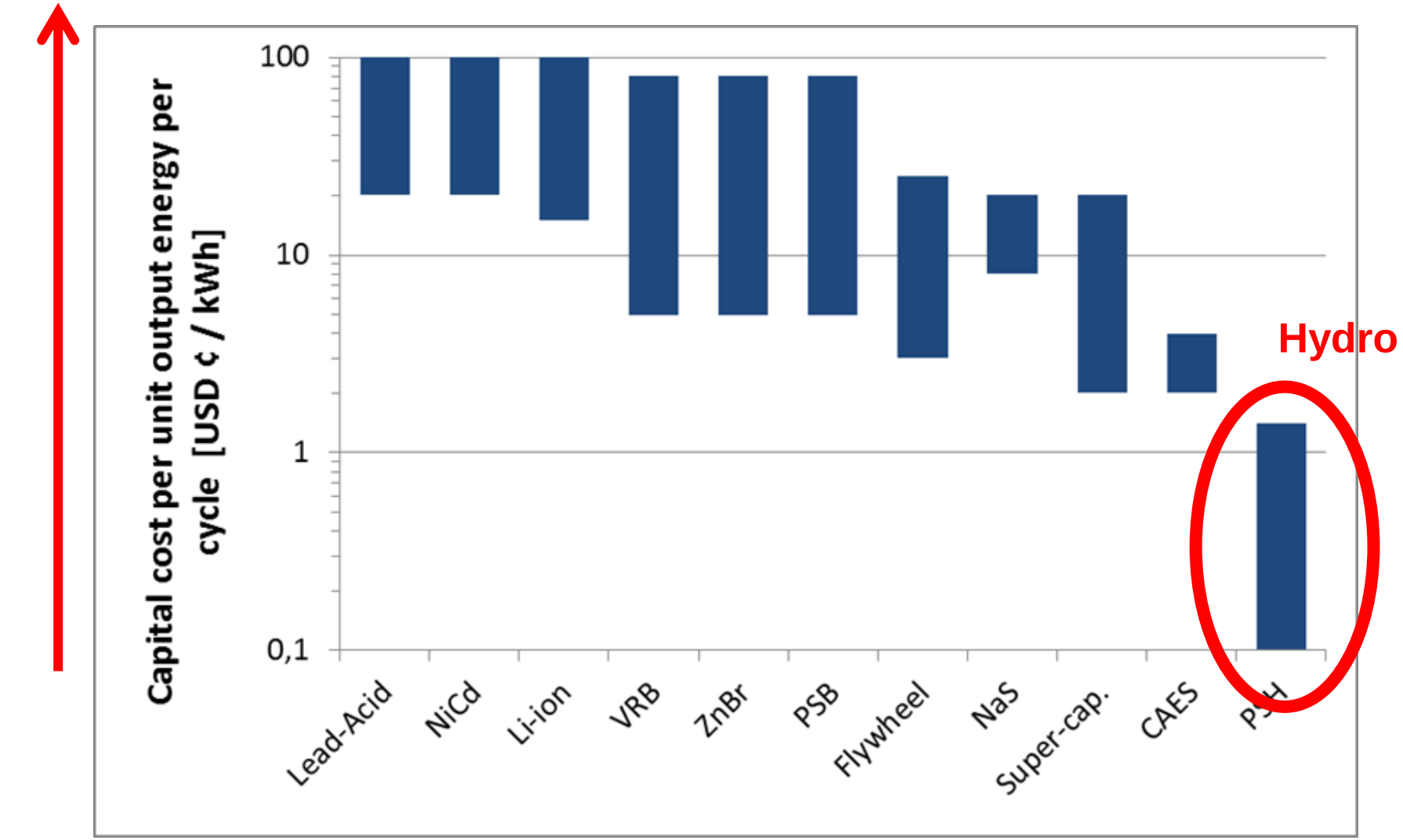
- Operates typically on seconds to minutes
- Used a lot in many other sectors
- Few large-scale energy storage applications

# World electric energy storage installed capacity 2012



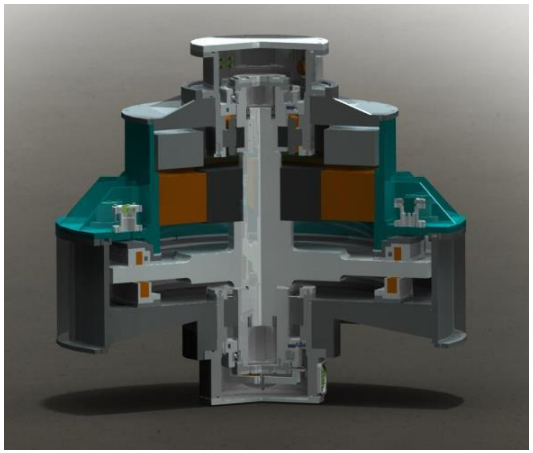



# Capital costs per cycle:



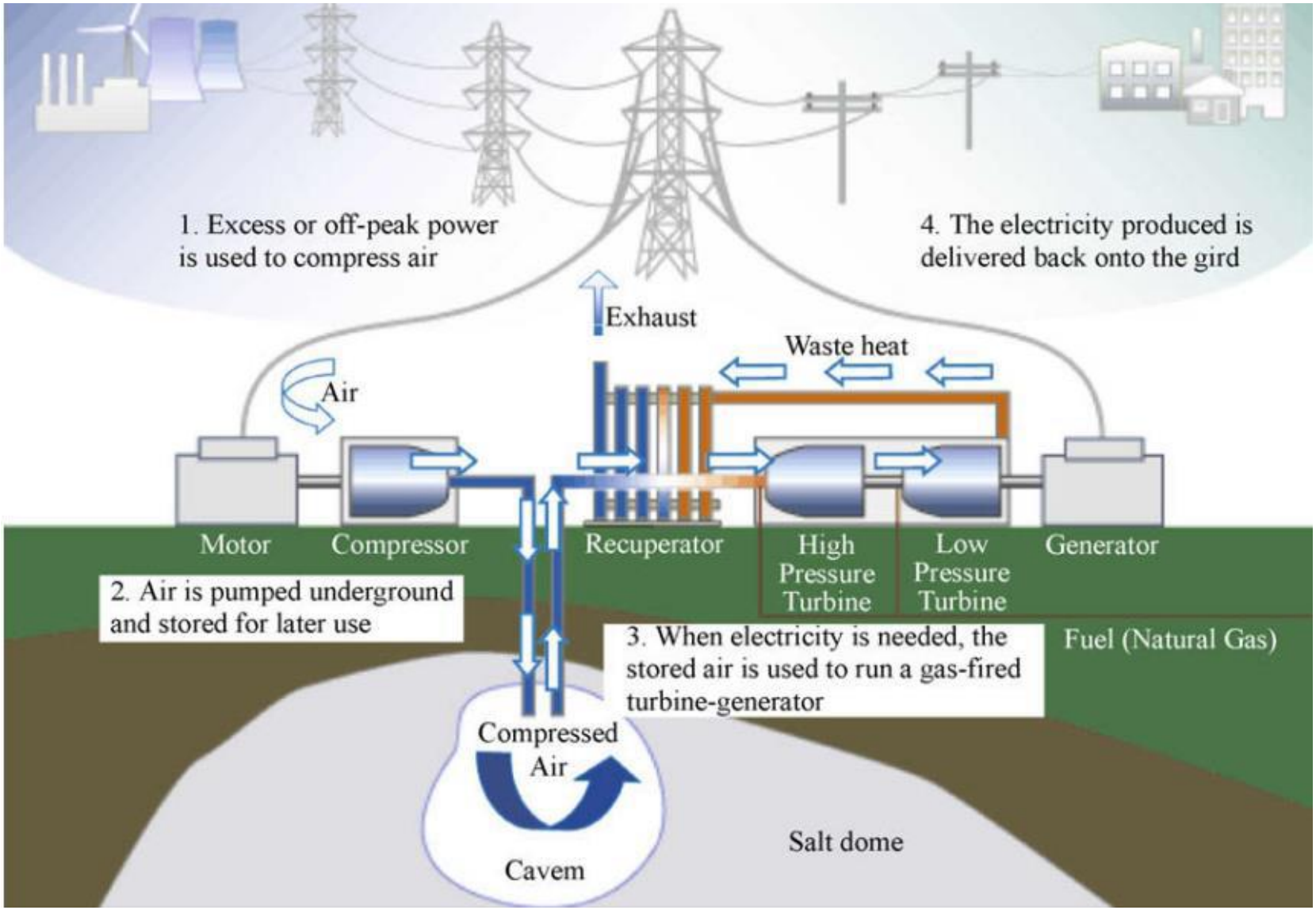
# Flywheels – kinetic energy storage

- Rotating mass
- High power and energy density
- Very fast regulation
- A large number of life cycles

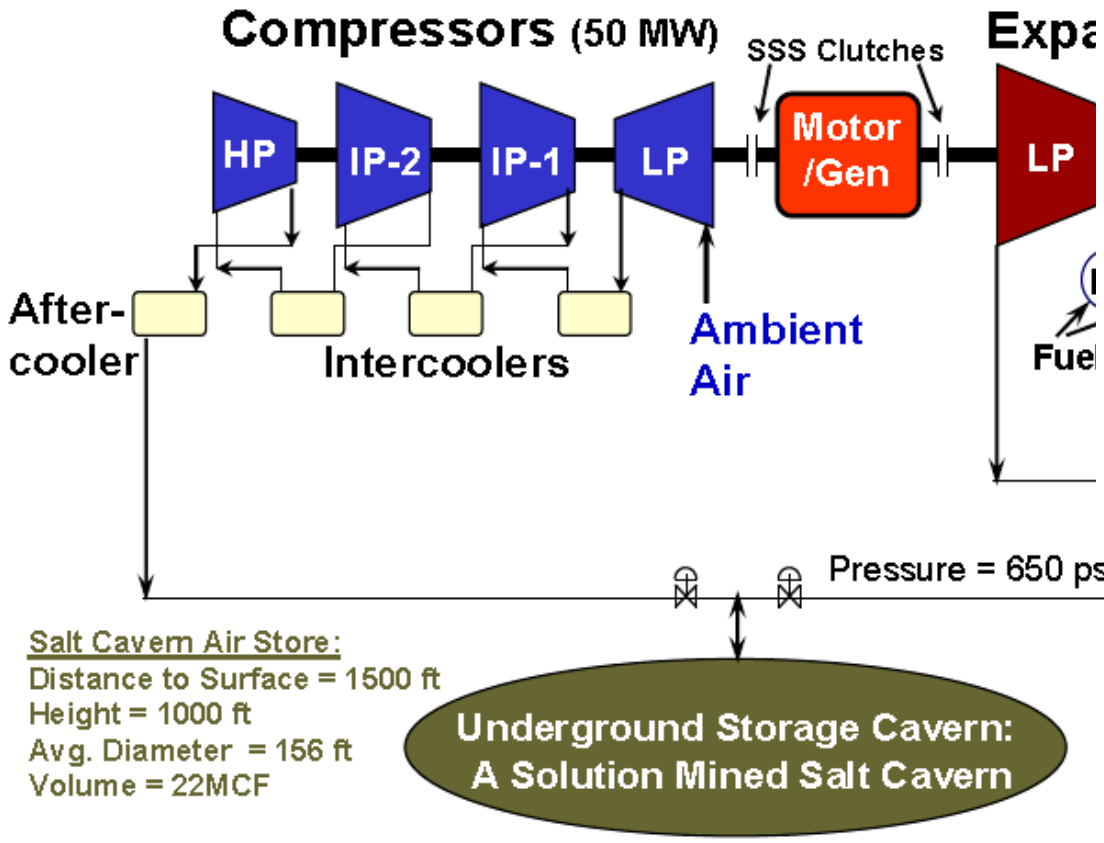
- Transportation
  - Electric and hybrid cars, buses
  - Light trains, trams, underground
  - Ferries
- Power system services
  - Grid stability
  - Frequency regulation
  - Voltage support
- Industry
  - Uninterrupted power supply
  - Cranes and elevators

# Compressed Air Energy Storage (CAES)




*From Luo and Wang*

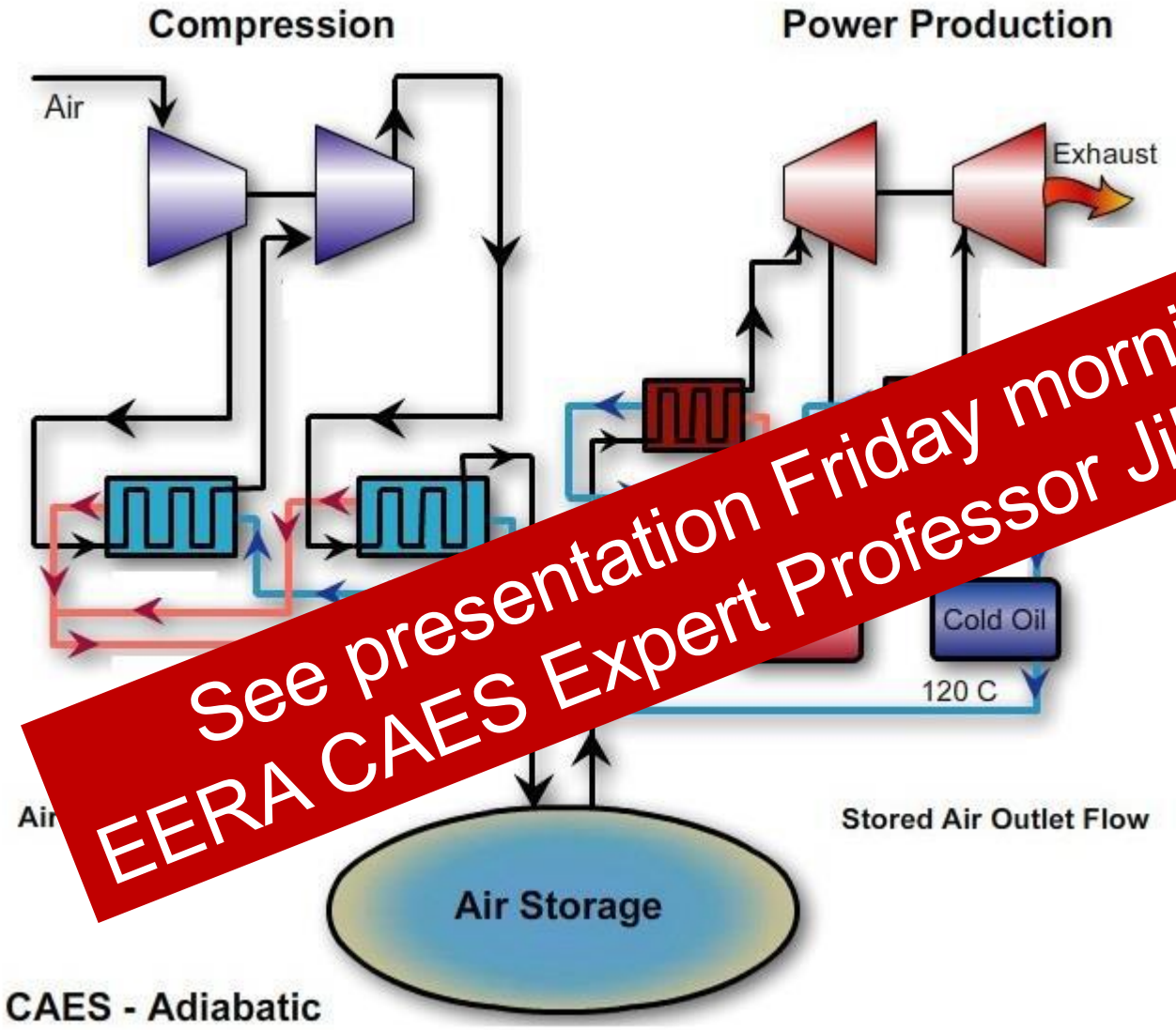
# McIntosh CAES plant
## (one of two commercial plants)




| | |
|---|---|
| Heat Rate | 4100 |
| Energy Ratio | 0.81 |

*From Luo and Wang*

# Adiabatic CAES

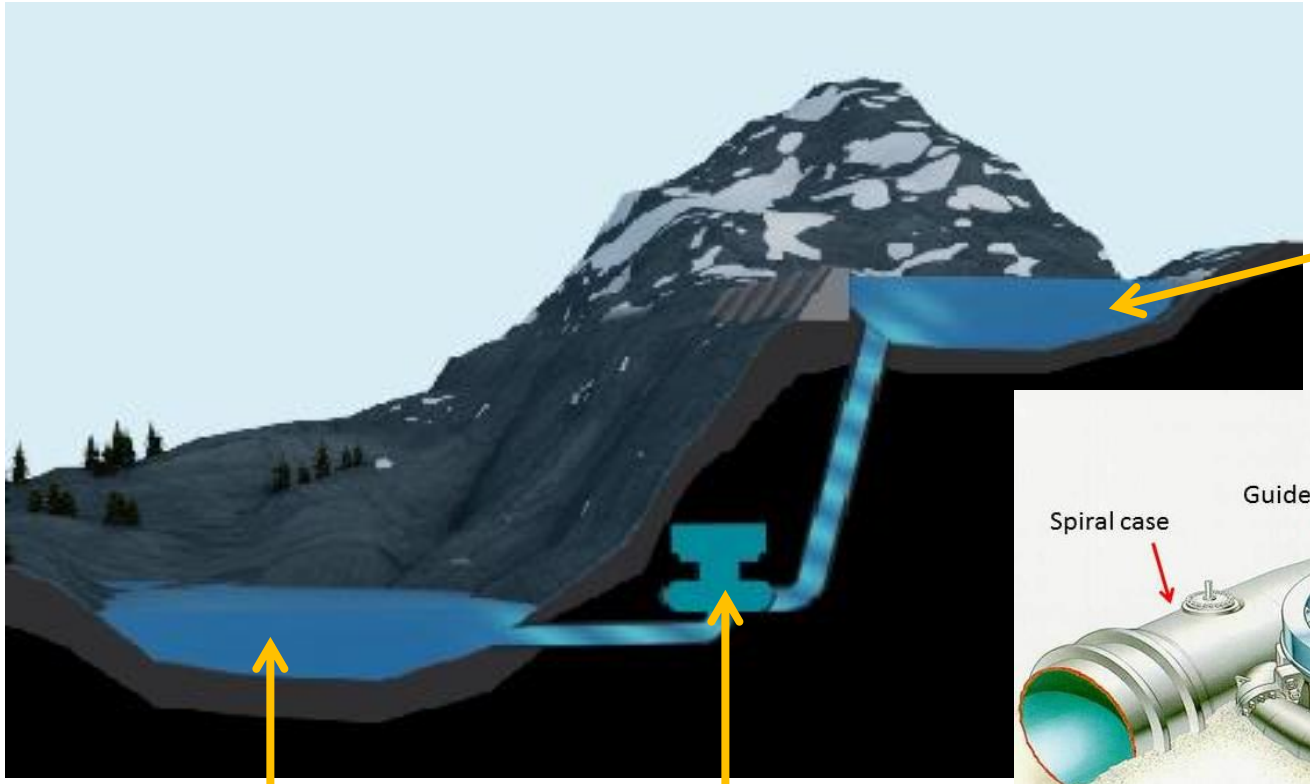



See presentation Friday morning by EERA CAES Expert Professor Jihong Wang

Small scale CAES: Competing with batteries

*From Luo and Wang*

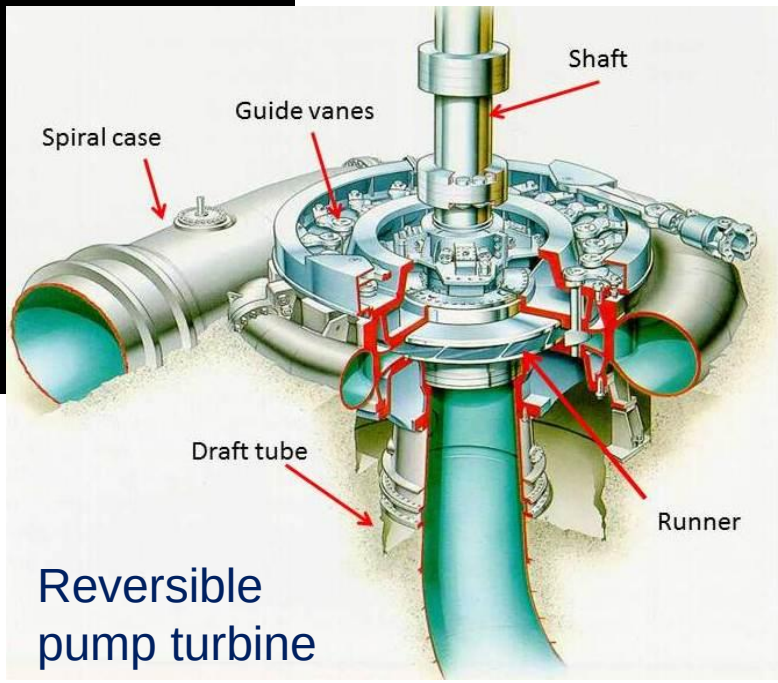
# Pumped Storage Hydropower principle



Upper reservoir

Lower reservoir

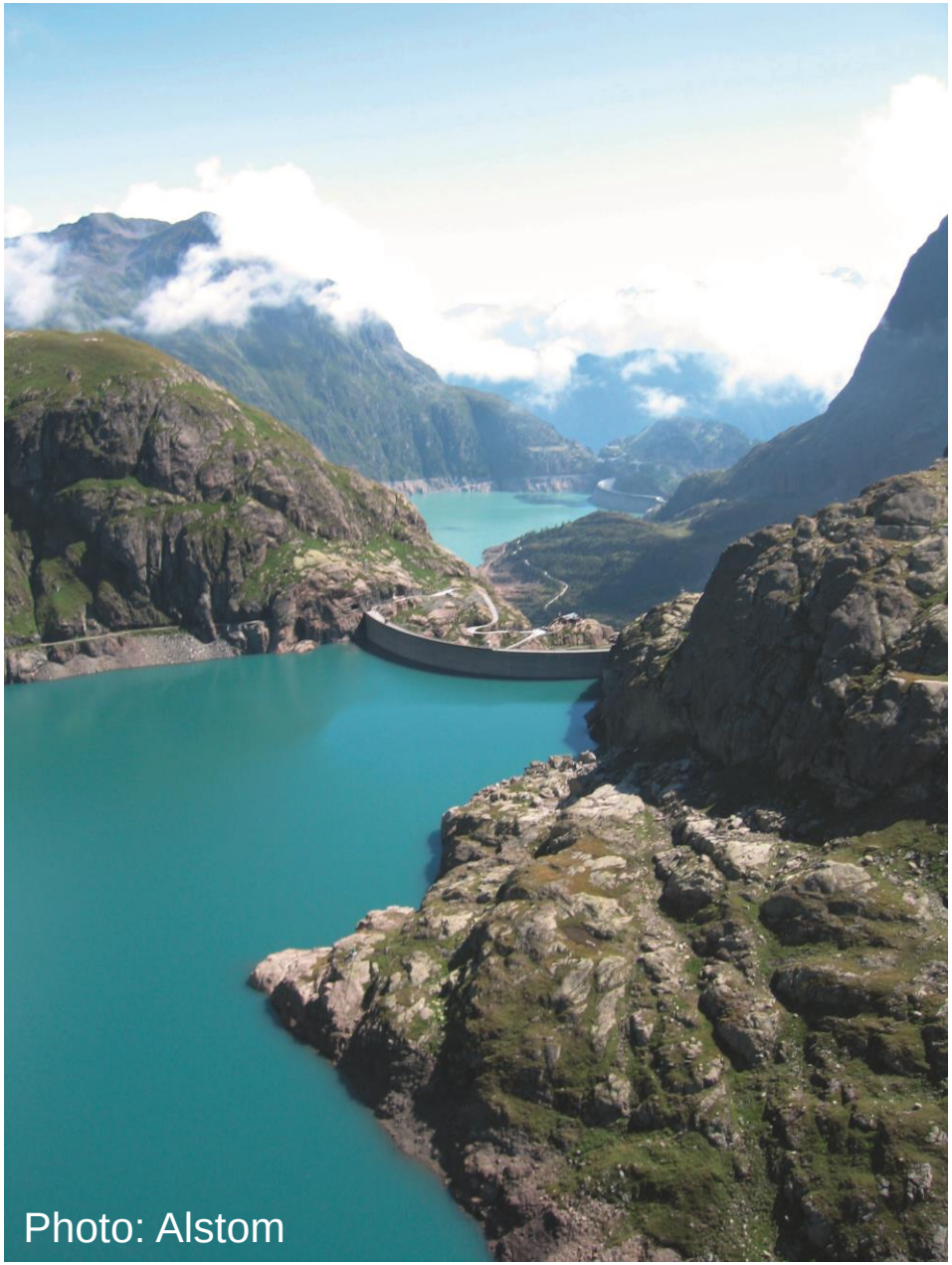
Underground turbine and pump




Reversible pump turbine

# Afourer, Marocco

# Nant de Drance, Switzerland



# Goldisthal, Germany

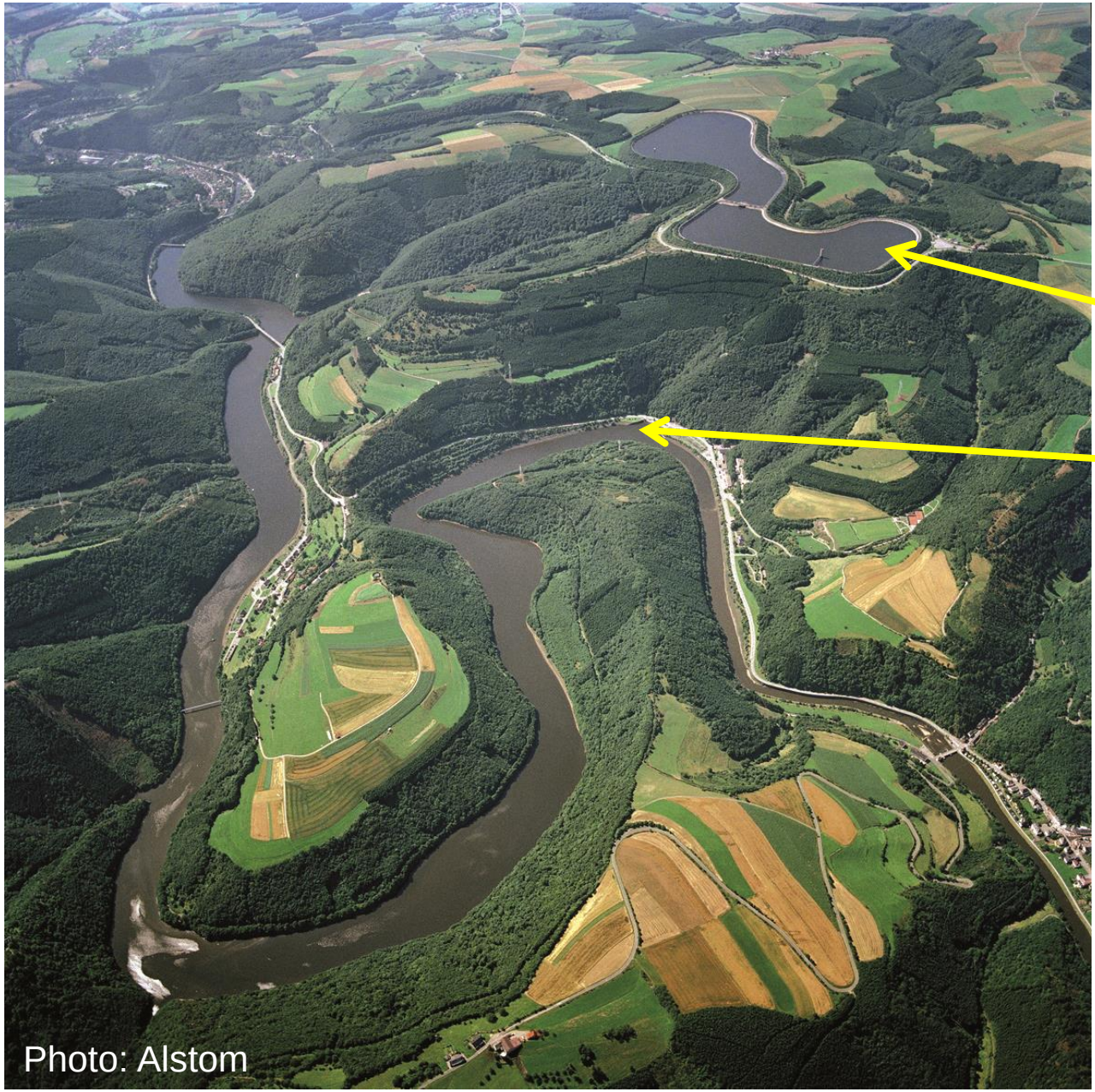
# Limberg II, Austria

# Grand Maison, France

1 800 MW turbine mode

1 275 MW in pump mode

***Courtesy from Rioual, EdF***

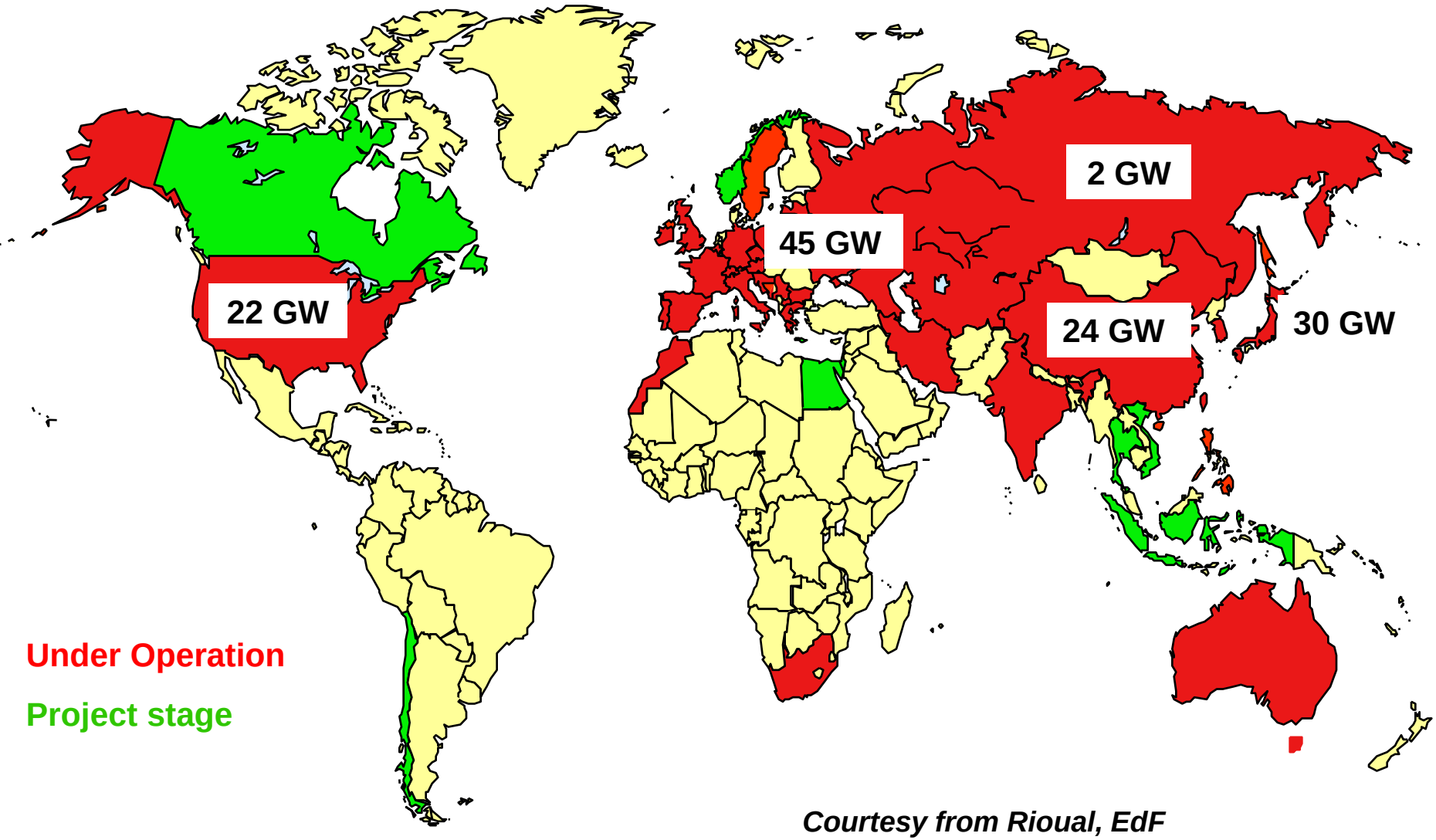



# Vianden, Luxemburg

Upper reservoir

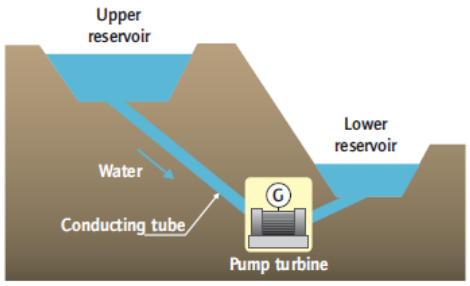
Lower reservoir:
The river

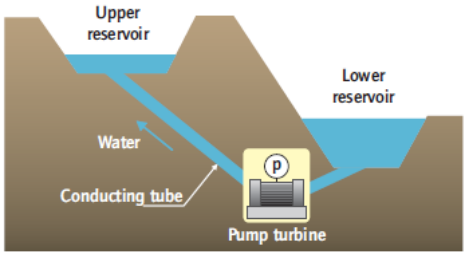
# Installed PSH world-wide: ~140GW




*Courtesy from Rioual, EdF*

# International PSP – Some facts




**Existing capacity worldwide: 140 GW (2011)**
**42 GW added since 2005 (7 GW/year)**
**Projections 2050: 500-700 GW**

## Leading PSP regions

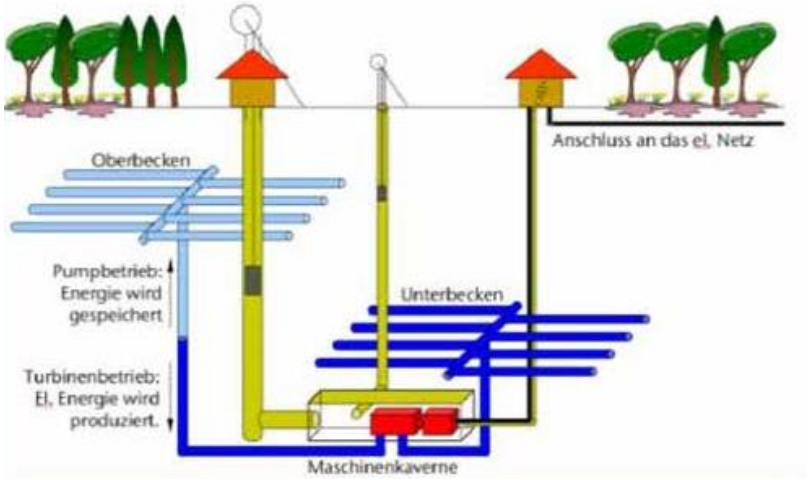
| | |
|---|---|
| EU | 45 GW |
| Japan | 30 GW |
| China | 24 GW |
| USA | 20 GW |

## Storage:

| | | |
|---|---|---|
| Spain | 17 PSP | 1500 GWh |
| Switzerland | 16 PSP | 369 GWh |
| France | 9 PSP | 184 GWh |
| Austria | 15 PSP | 125 GWh |

# New technologies – pumped storage

- Underground PSP




- Sub-sea PSP
- Artificial island PSP
- Retrofitting reservoir hydro
- Variable speed reversible pump turbines

- Salt water PSP

*Okinawa PSP - Japan*

  - No access to lakes
  - Scarce water resources
  - Isolated grids (islands)
  - Extra maintenance (salt)

# Hydropower – supporting other renewables

Solar

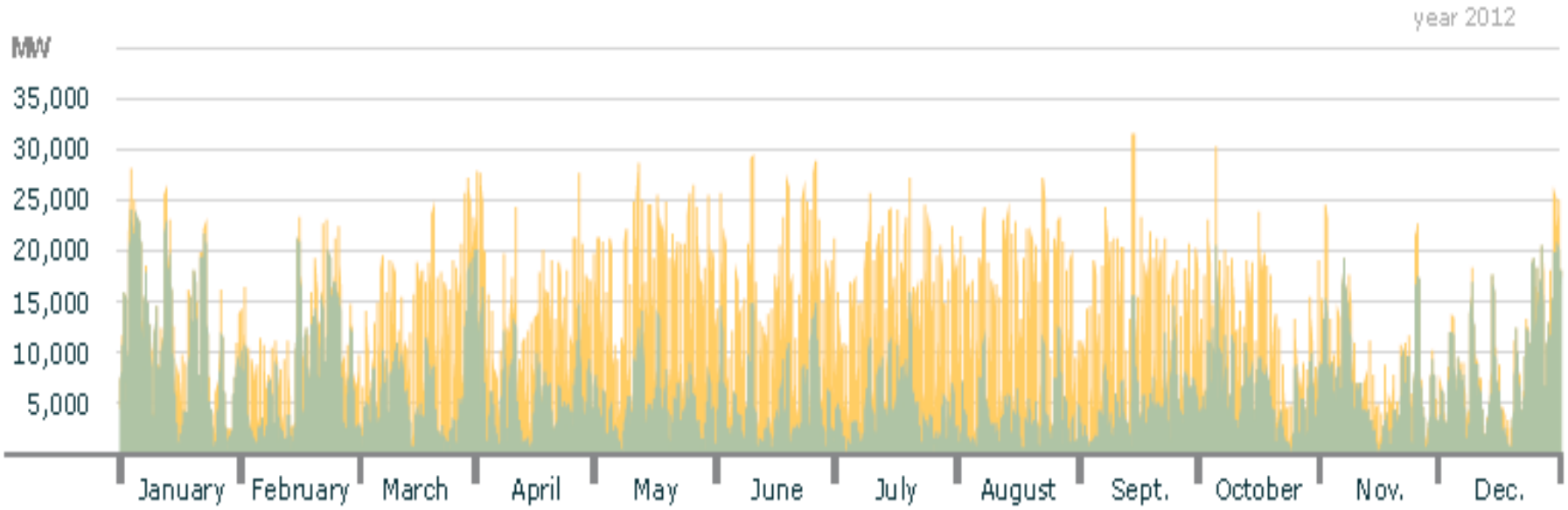

Wind


CEDREN studies in 2011 and 2012: How can Norway contribute?

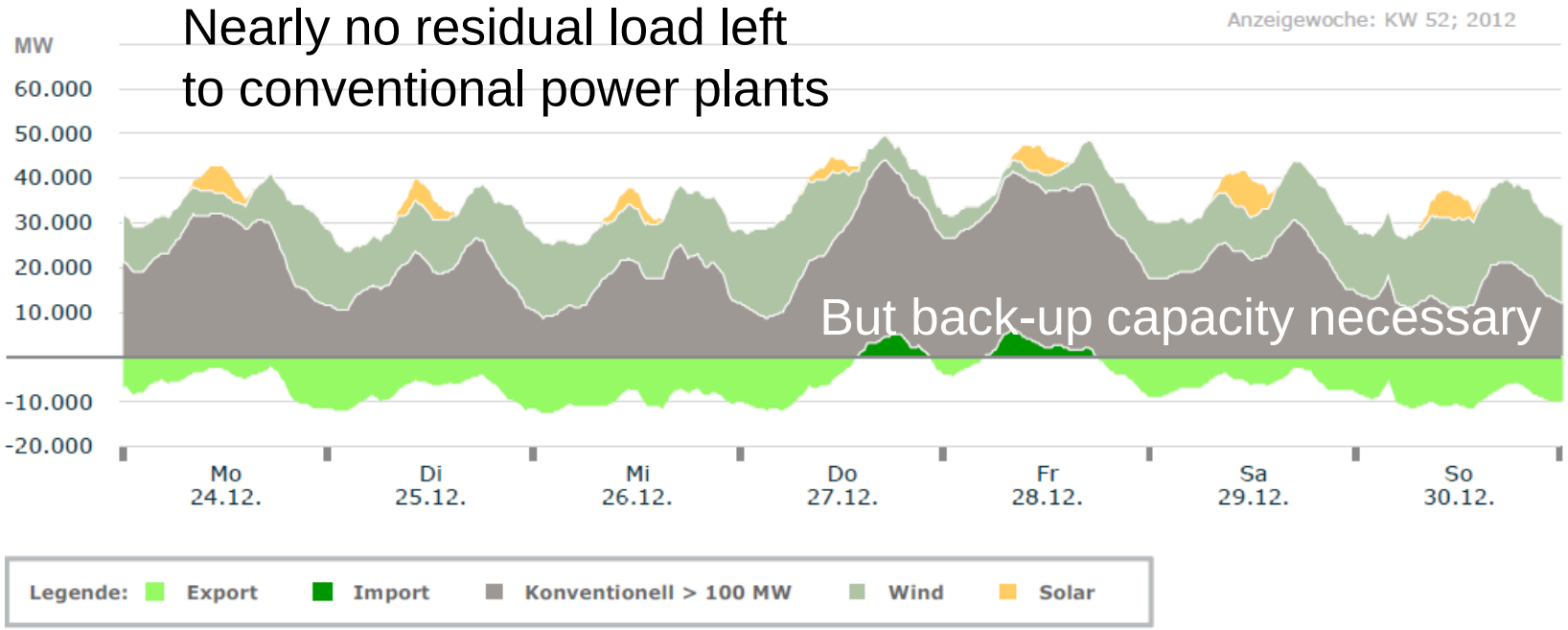
Main problem with
Wind and Solar Power:

- Intermittency
- Highly variable output
- Low predictability
- Non-Dispatchable

**Actual production solar and wind** (Germany 2012)

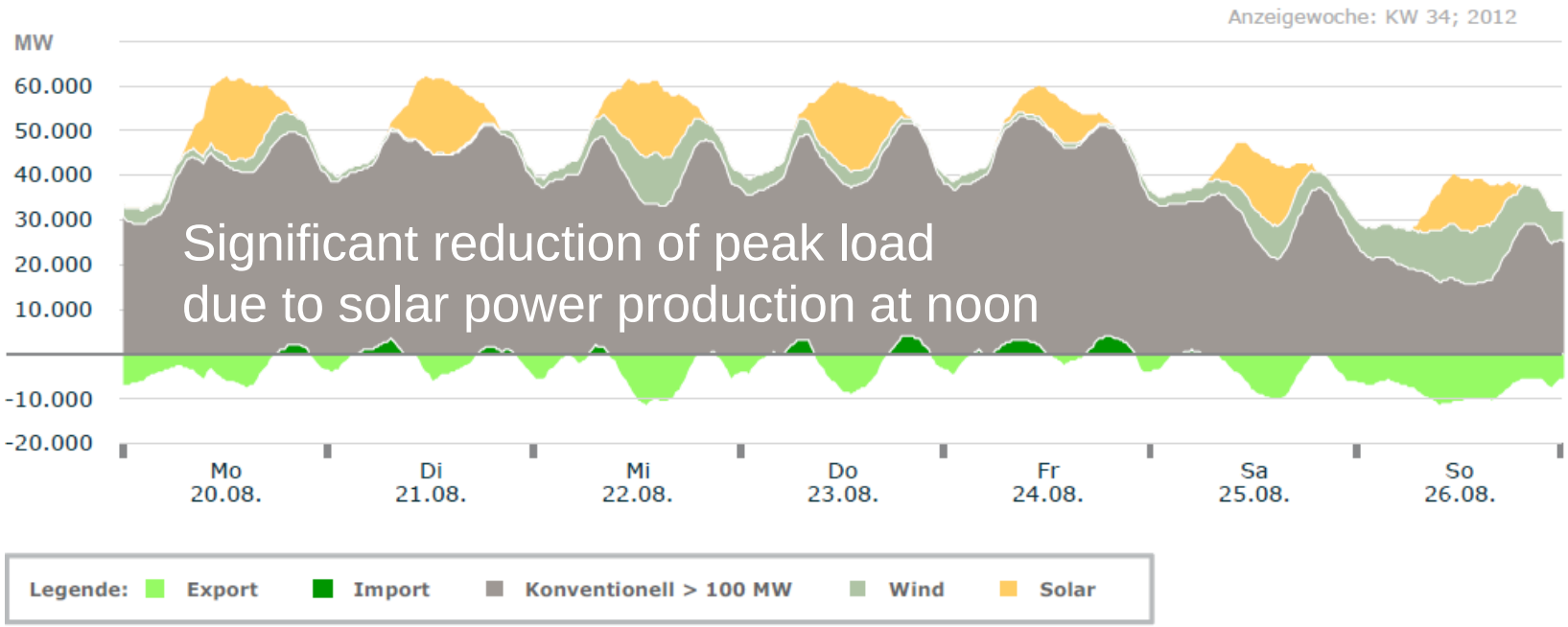


# RES challenges
## High Wind power production



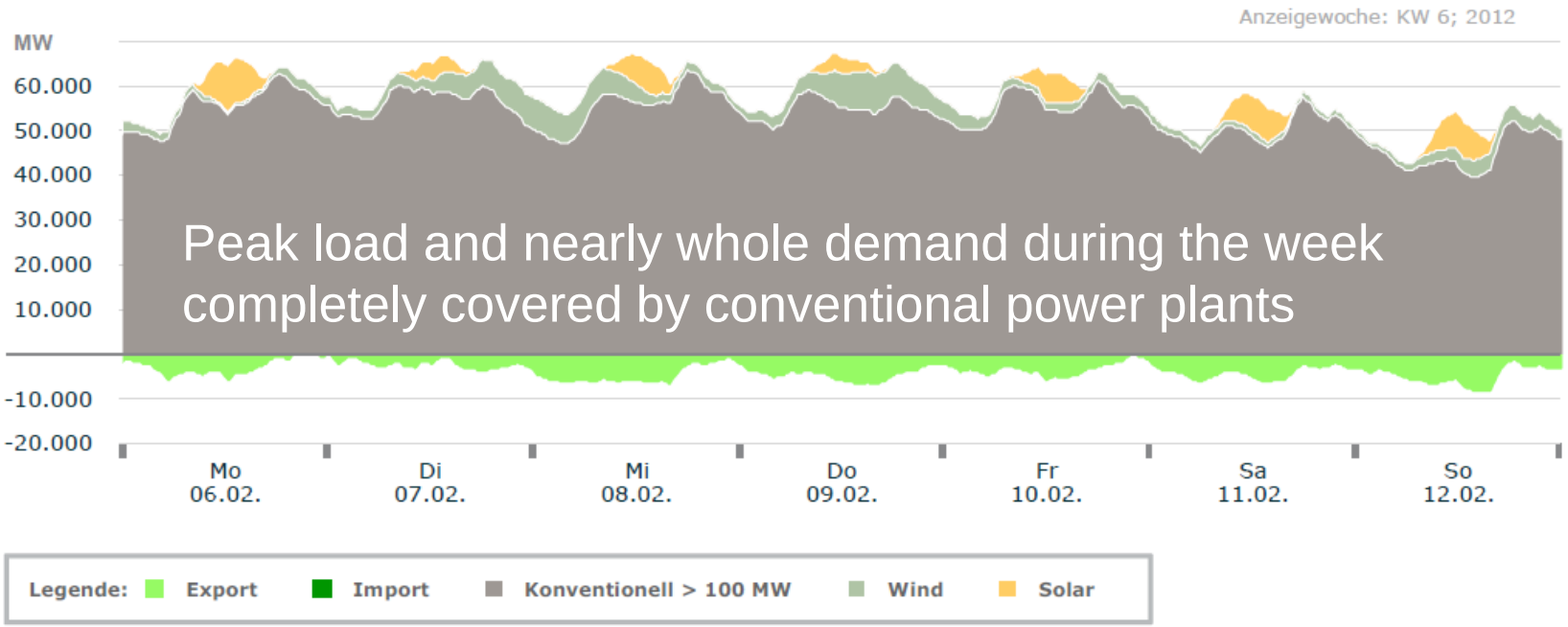

Source: Burger, B. "Electricity production from solar and wind energy in 2012", Fraunhofer ISE, presentation, February, 2013
URL: http://www.ise.fraunhofer.de/en/renewable-energy-data

# RES challenges
## High Photovoltaic production



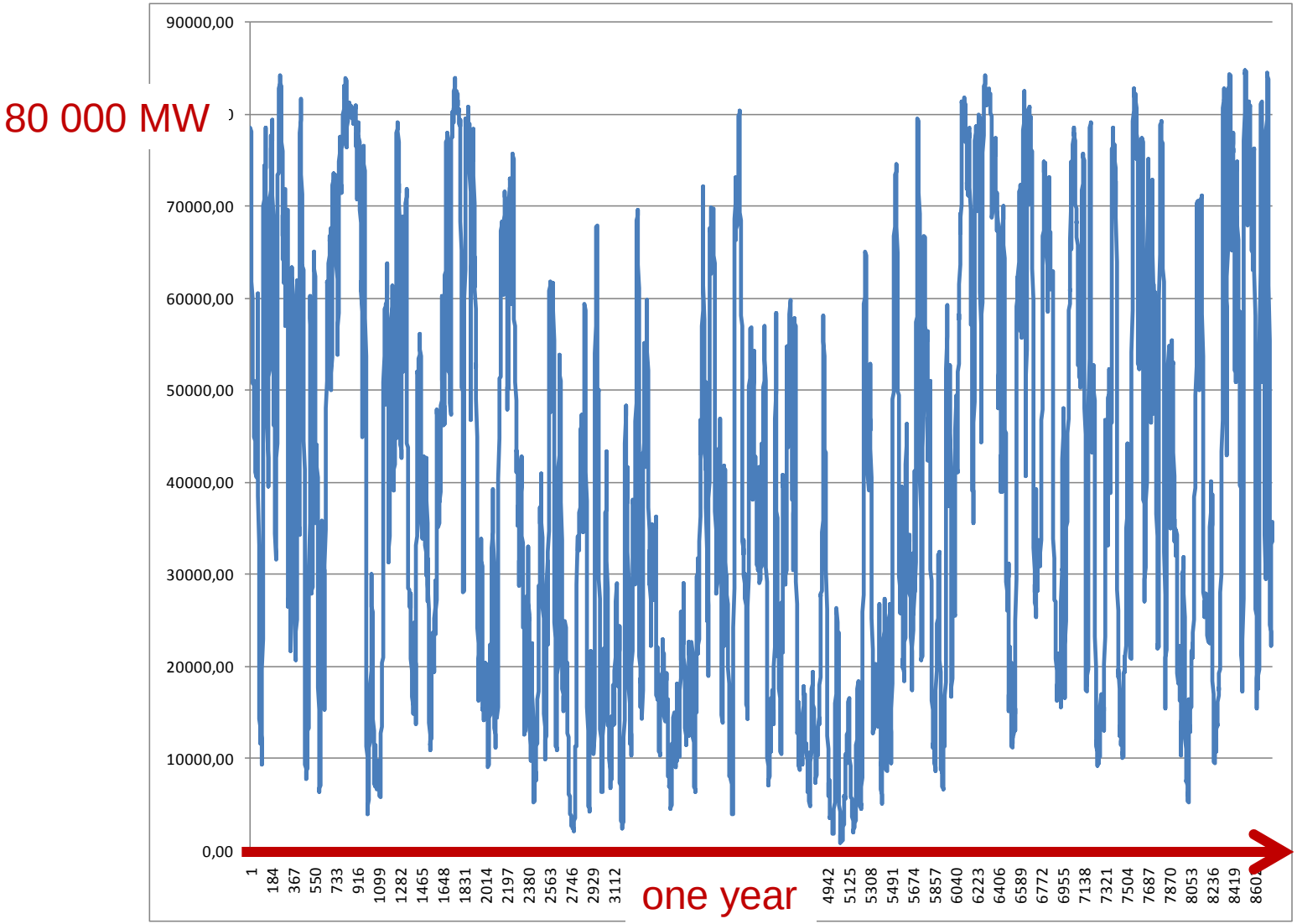

Source: Burger, B. "Electricity production from solar and wind energy in 2012", Fraunhofer ISE, presentation, February, 2013
URL: http://www.ise.fraunhofer.de/en/renewable-energy-data

# RES challenges
## No production from RES

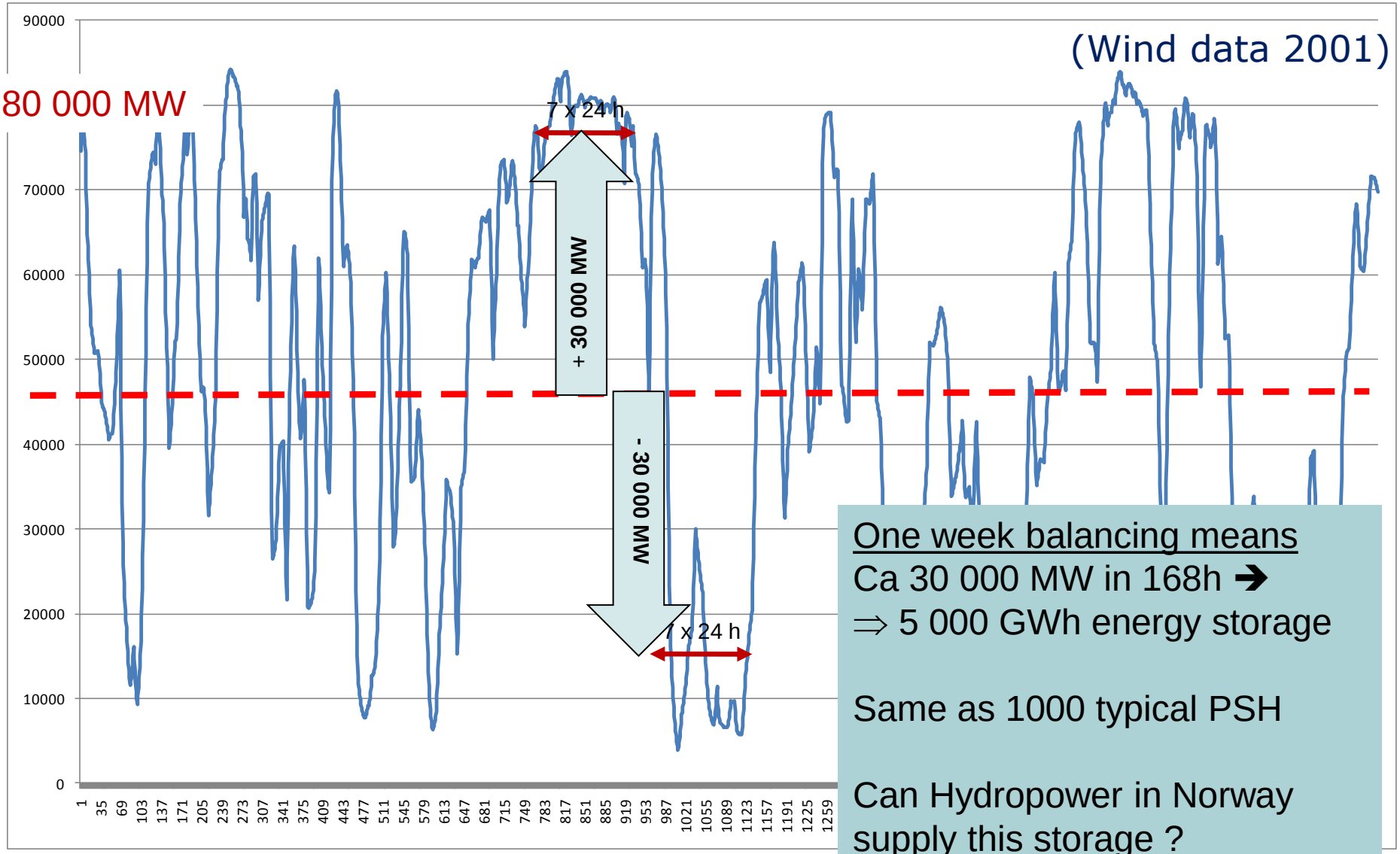



Source: Burger, B. "Electricity production from solar and wind energy in 2012", Fraunhofer ISE, presentation, February, 2013
URL: http://www.ise.fraunhofer.de/en/renewable-energy-data

# Simulated wind production in the North Sea area in 2030 – 95 000 MW installed capacity



# Wind Power North-Sea Region - Jan – March




<u>One week balancing means</u>
Ca 30 000 MW in 168h ➔
⇒ 5 000 GWh energy storage

Same as 1000 typical PSH

Can Hydropower in Norway supply this storage ?

# Hydropower in Norway – Resource base

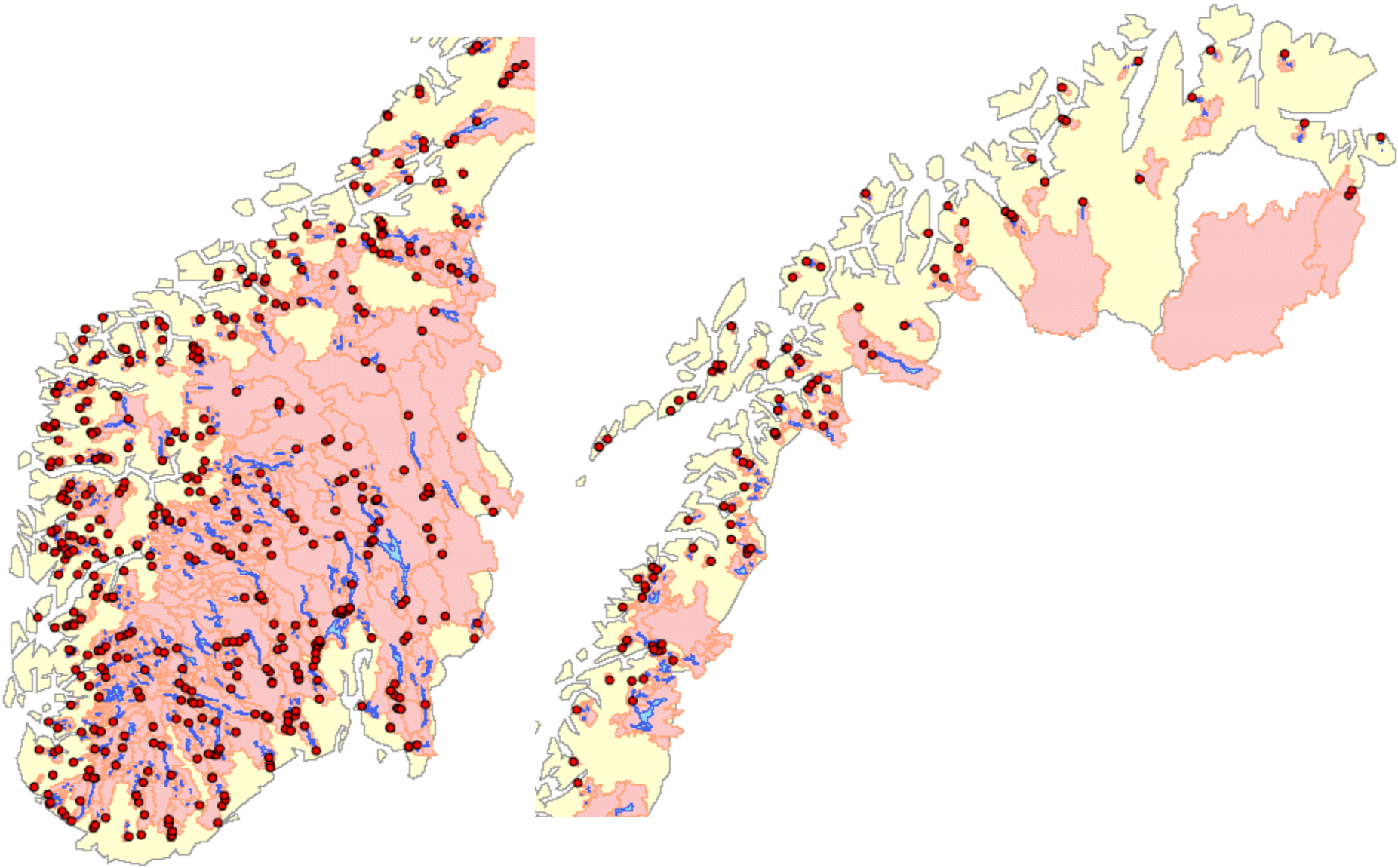
Water, high head

Large natural reservoirs

# Norwegian hydropower

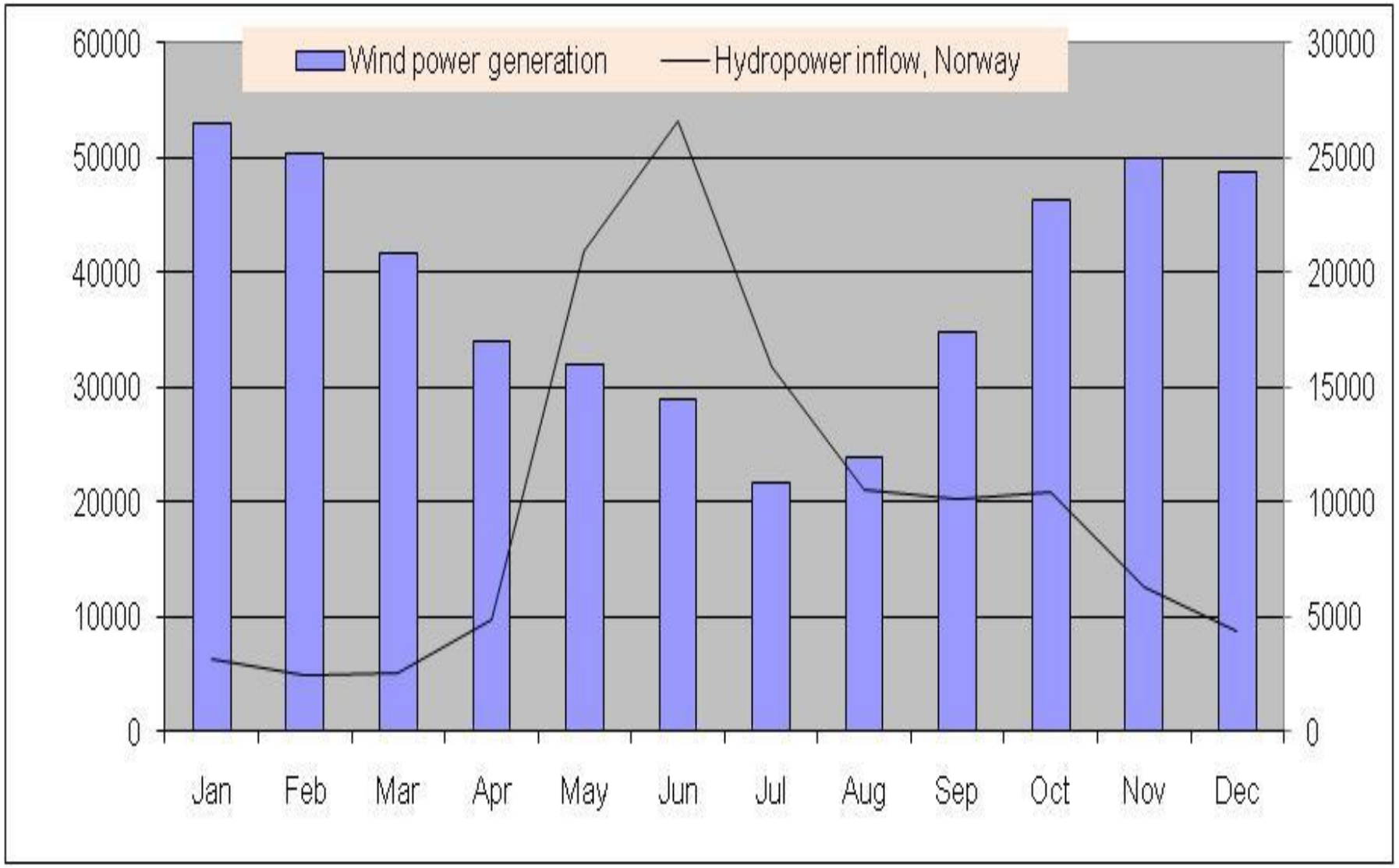
Solid rocks providing great opportunities to hide penstock and power plants inside the mountains

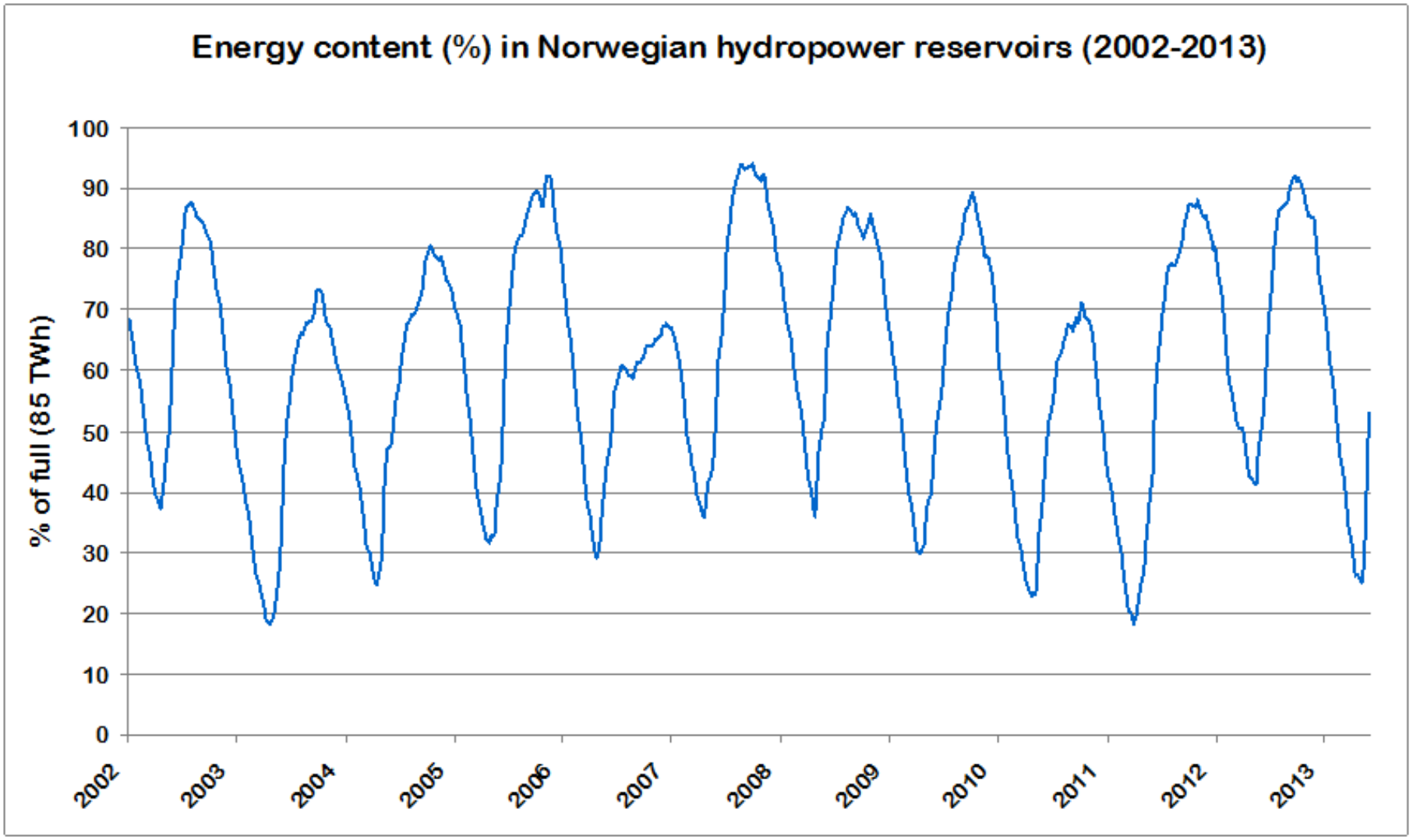
# 333 Large hydropower stations in Norway




Blåsjø
7.8TWh RESERVOIR
(1000 times Goldistal)

# Wind and hydropower seems like a good match



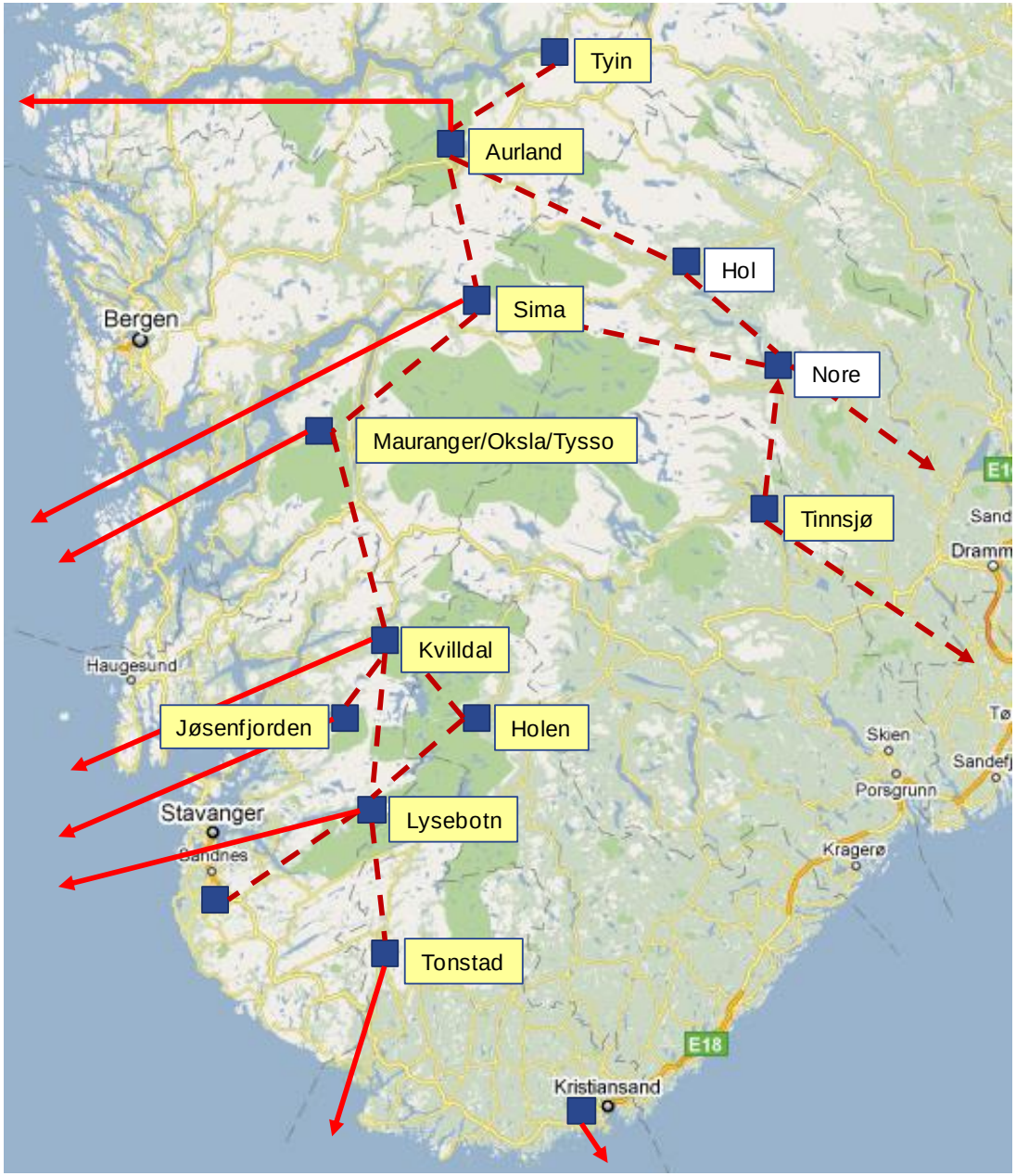

Energy content (%) in Norwegian hydropower reservoirs (2002-2013)
% of full (85 TWh)
100
90
80
70
60
50
40
30
20
10
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

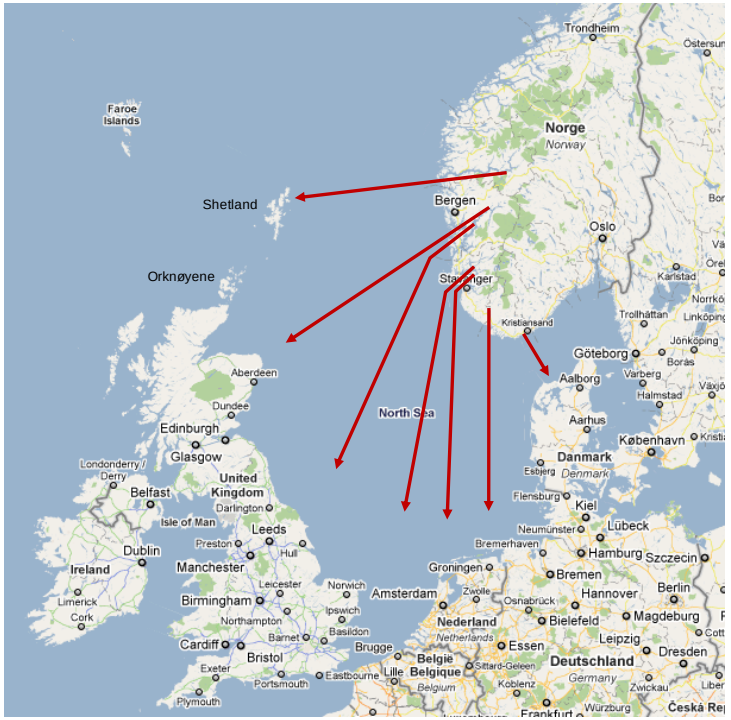
# Norwegian hydro and Danish wind



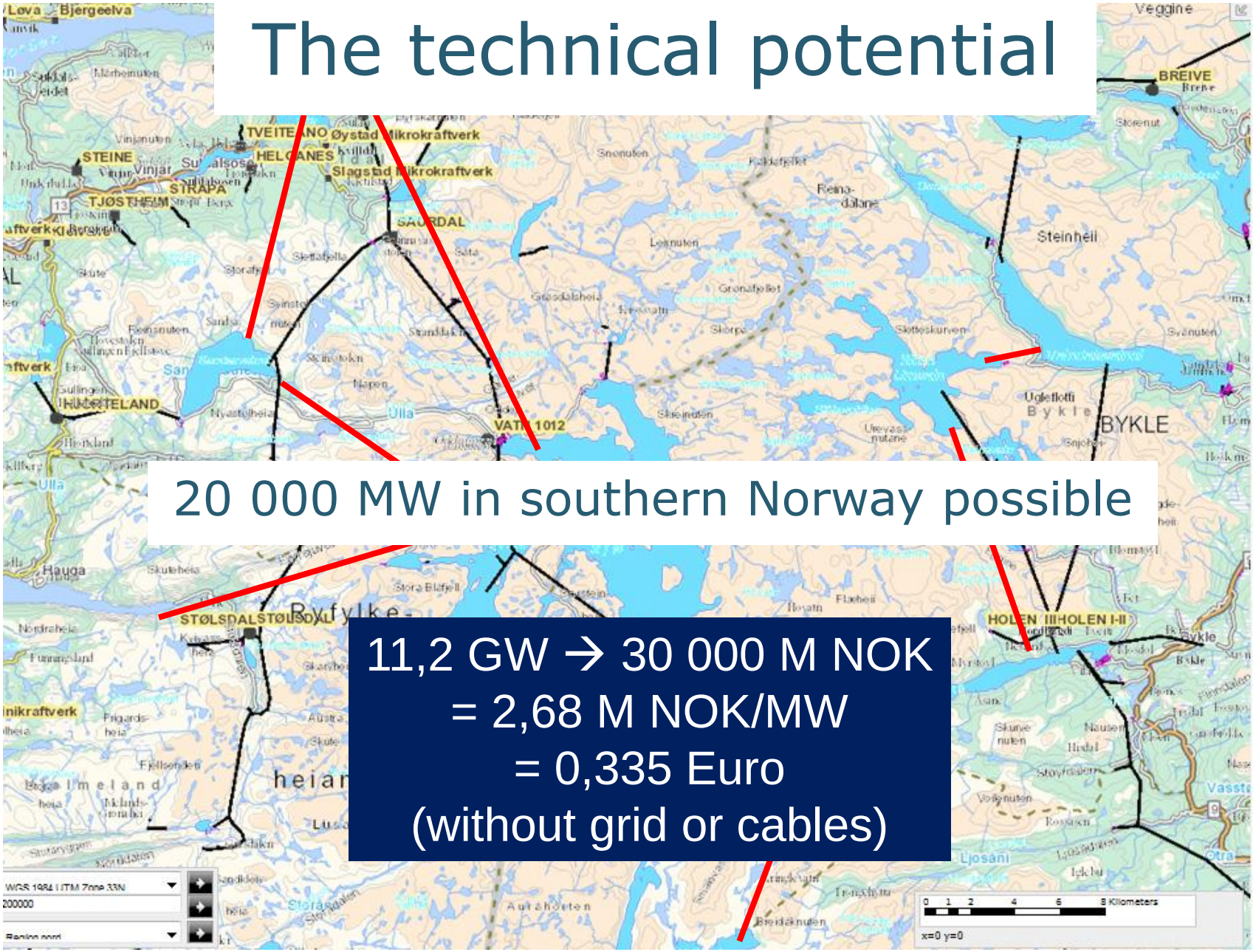
Danish wind cover underproduction

# CEDREN Case study 2030



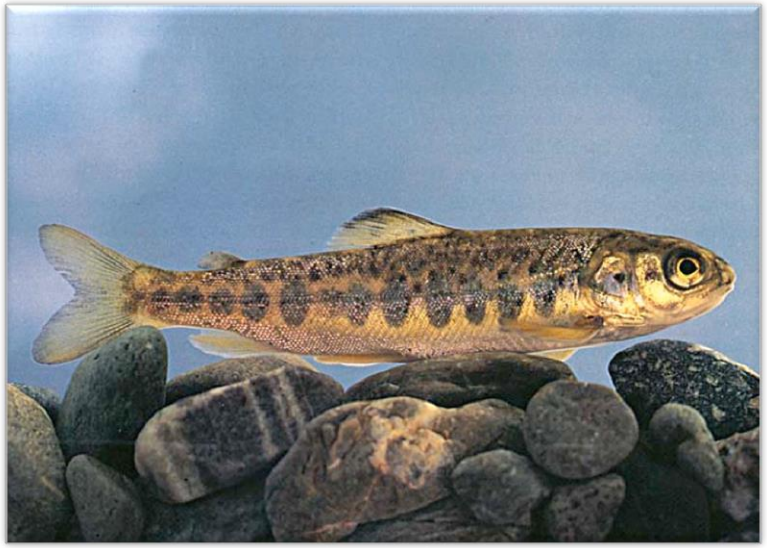
# The technical potential



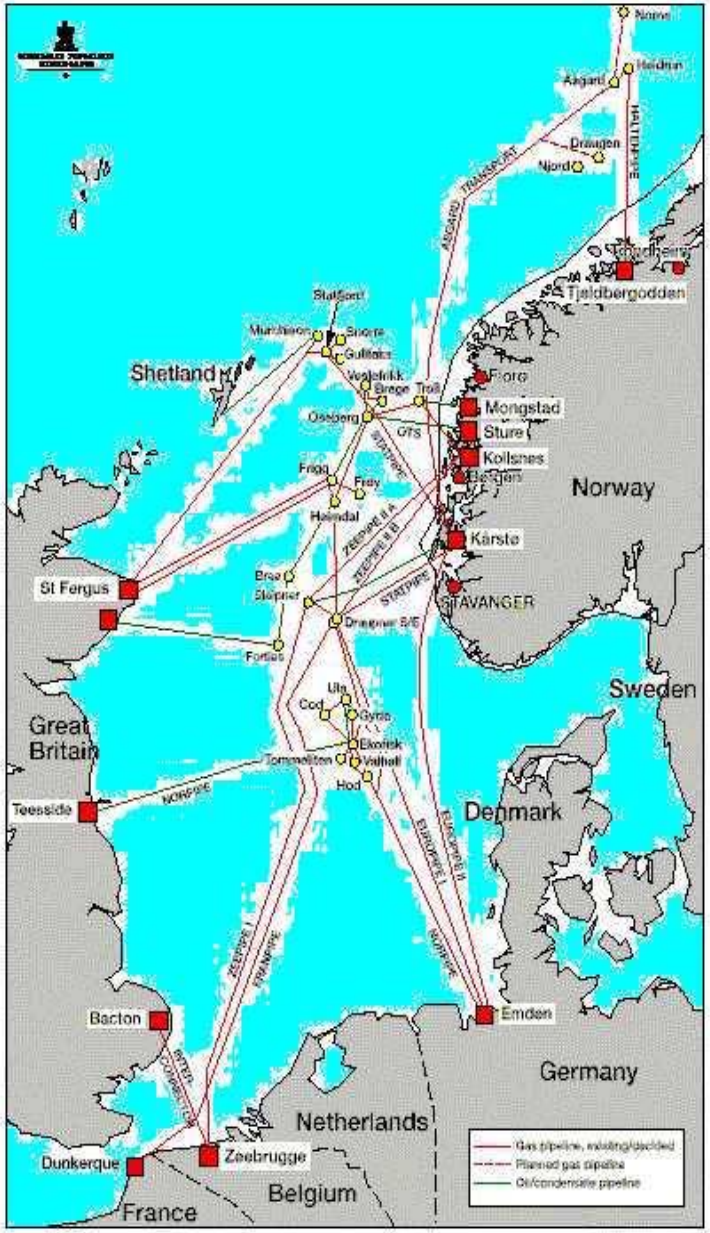

20 000 MW in southern Norway possible

11,2 GW → 30 000 M NOK
= 2,68 M NOK/MW
= 0,335 Euro
(without grid or cables)

# Environmental impacts

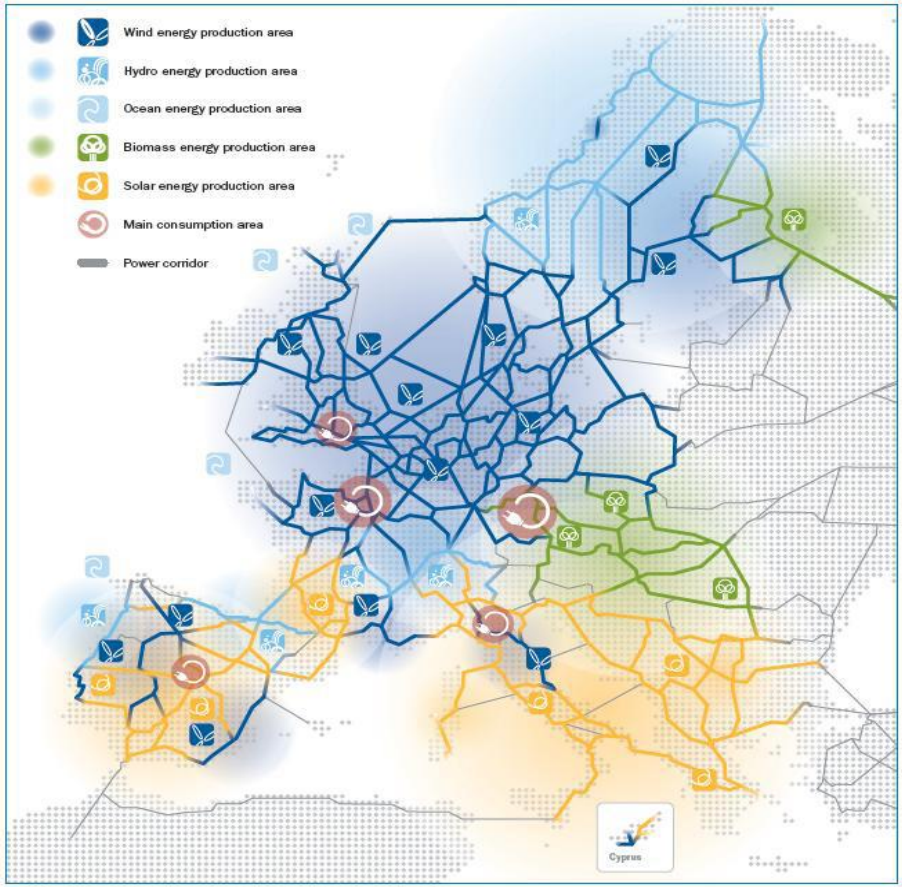


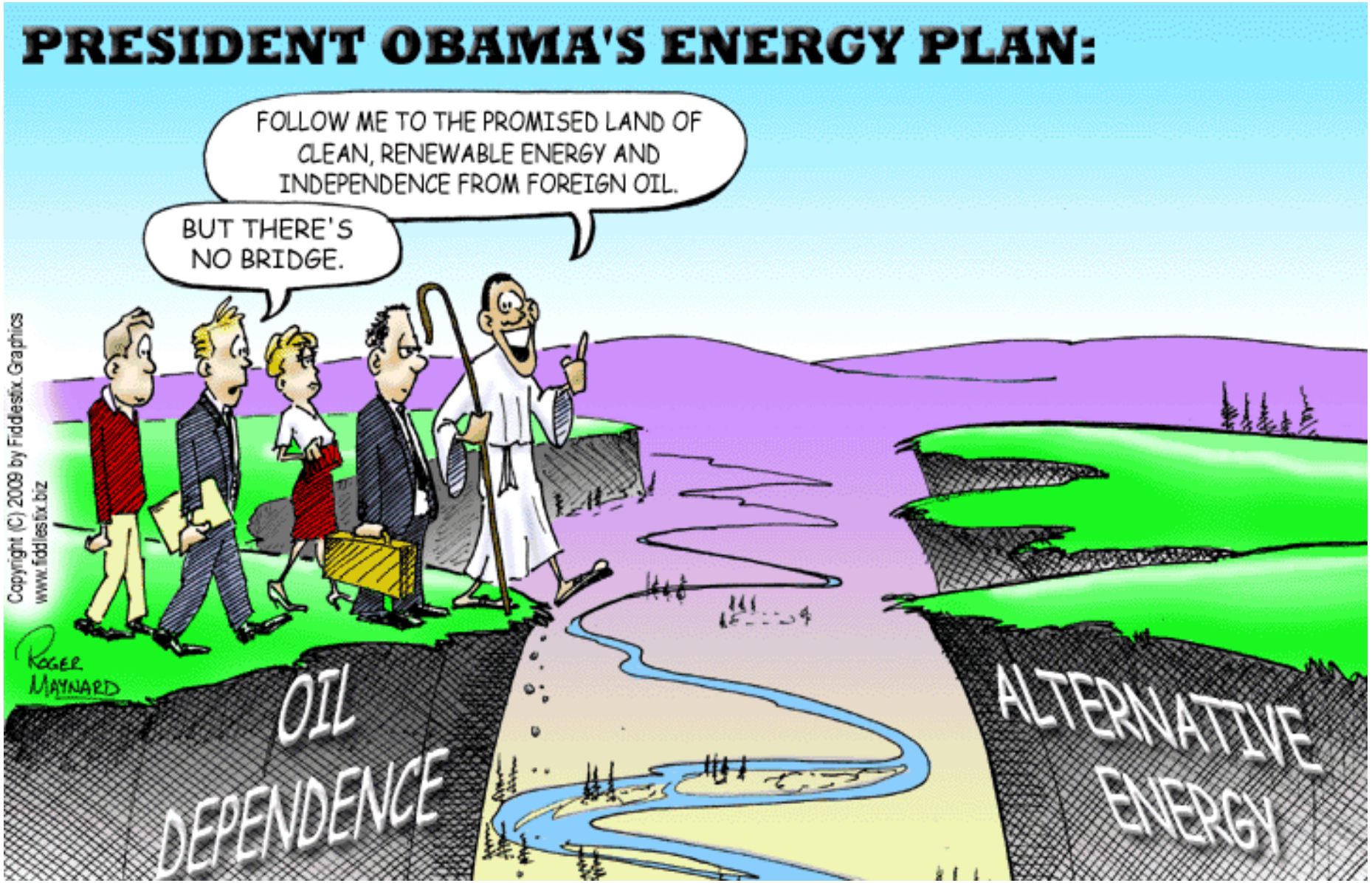
# Social acceptance

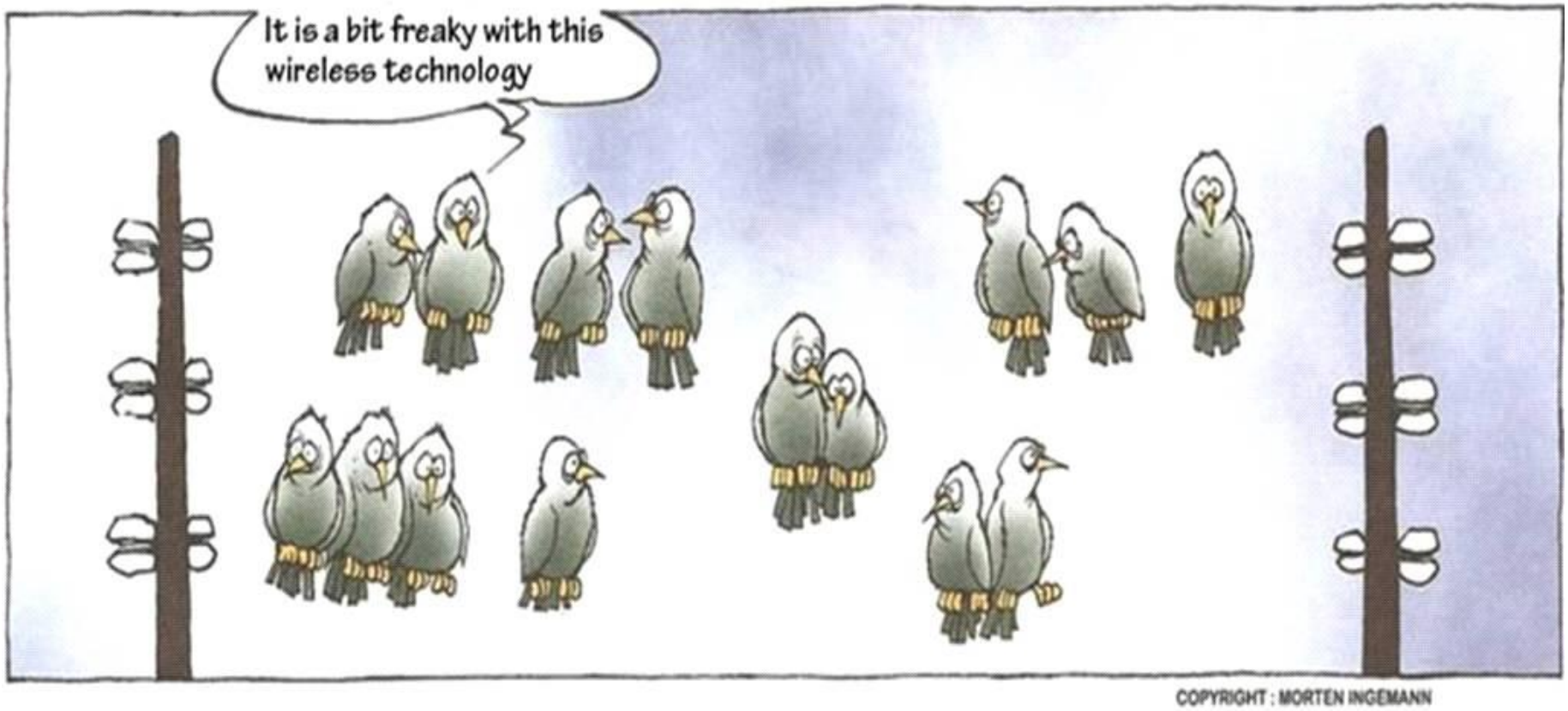



← Natural gas grid today

Can we establish a similar *electricity* grid for exchange?




PRESIDENT OBAMA'S ENERGY PLAN:
FOLLOW ME TO THE PROMISED LAND OF CLEAN, RENEWABLE ENERGY AND INDEPENDENCE FROM FOREIGN OIL.
BUT THERE'S NO BRIDGE.
Copyright (C) 2009 by Fiddlestix Graphics
www.fiddlestix.biz
ROGER MAYNARD
OIL DEPENDENCE
ALTERNATIVE ENERGY




- Uncertain future – many scenarios
- Rapid changes may come (…Fukoshima)
- Hydro reservoirs = always an excellent energy storage
- We probably need governmental agreements and new markets
- Norwegian hydro: Large opportunity for Europe