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Digital Systems

28 November 2022

Small Modular Reactors (SMRs) Energy Solution for the Future

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SMR Technology Overview



Image from: CBC

What is an SMR?

- A Small Modular Reactor is a nuclear reactor with a power output of 10-300 MWe [*OECD Nuclear Energy Agency*]. (M-R <10MWe)
- SMRs are often integral and modular, typically designed for factory fabrication, taking advantage of the benefits of the economies of series, and to be transported and assembled on-site, resulting in shorter construction times.
- These are some of the key elements for SMR competitiveness.
- There are currently over 70 SMR designs in development worldwide.



Image from: energypost.eu

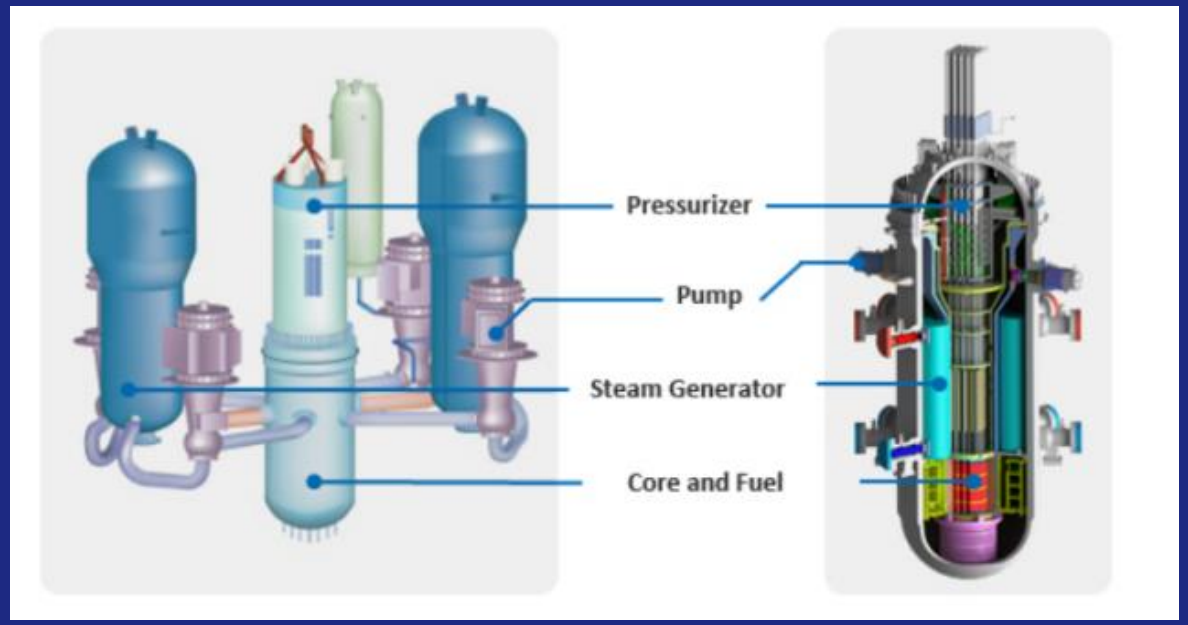


Image from: neutronbytes.com

Comparing the SMRs to the conventional model

Small Modular Reactor

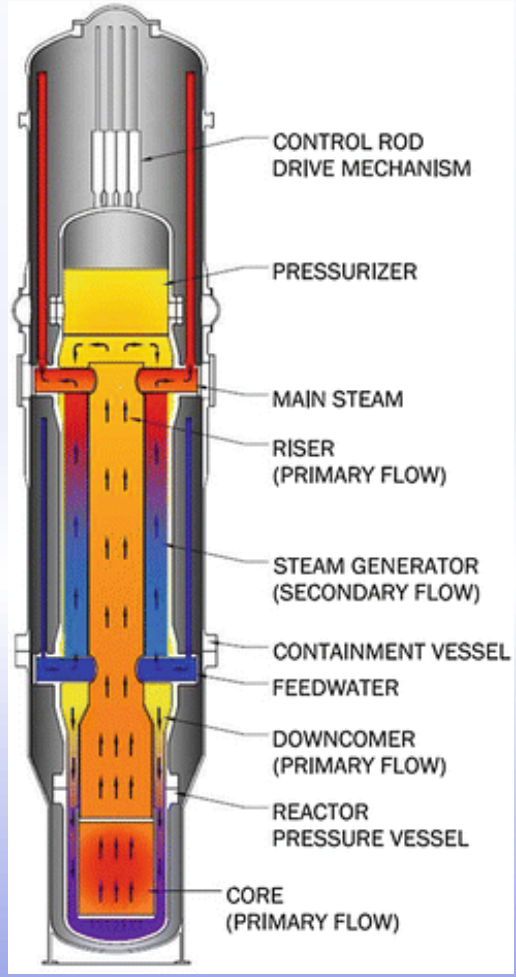
- Electrical output per unit 10-300 Mwe
- Modular design built in factory and last 10% assembled on site
- Site footprint 195 Mwe ≈ 7 hectare/17 acres
- Potential uses: electricity generation, hydrogen production district heating, desalination
- Safety Systems: Passive, inherent negative reactivity feedback
- Scalable: the ability to add additional units to the site based on growth and needs
- Load following capability

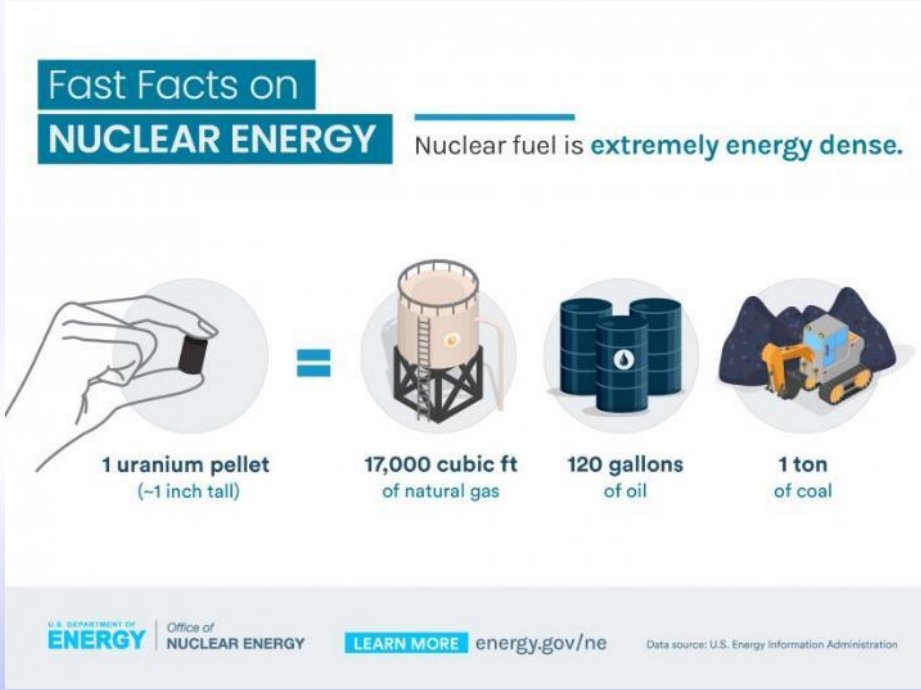
Conventional Design

- Electrical output per unit 700-1400MWe
- Some modular design but 70 -80% constructed onsite
- Site footprint 1000 Mwe ≈ 259 hectare/640 acres
- Potential uses: electricity generation, support of hydrogen production
- Safety Systems: Active systems requiring electrical power
- Normally the site is designed for 1 to 2 units due to size
- Normally used for base load

Safer designs with less waste

- SMRs use passive safety systems, which rely on the natural laws of physics to shut down and cool the reactor in abnormal conditions
  - Examples: gravity, differential pressure, natural heat convection
- Passive safety systems require no power source, and no human actions in order to initiate, so they are not affected if there is a loss of power, and the risk of human error is significantly reduced.
- Smaller core, less frequent refueling and the ability to recycle spent fuel from conventional plants means that less radioactive waste is produced.





There are 70+ SMRs currently in development

- SMR design types
  - Water-cooled, including:
    - Light water reactor (LWR)
    - Heavy water reactor (HWR)
    - Pressurized water reactor (PWR)
    - Boiling water reactor (BWR)
  - High temperature gas cooled (HGTR), including:
    - Pebble bed reactor (PBR)
  - Fast neutron, including:
    - Liquid metal fast reactor (LMFR)
    - Gas modular fast reactor (GMFR)
  - Molten salt, including:
    - Chloride salt cooled reactor
    - Fluoride salt cooled reactor

- Major SMR manufacturers
  - Seaborg (Denmark)
  - NuScale (USA)
  - Southern Company / TerraPower (USA)
  - X-energy (USA)
  - Westinghouse (USA)
  - Holtec (USA)
  - Terrestrial Energy (Canada)
  - Rolls-Royce (UK)
  - Swedish Modular Reactors / Uniper

Current SMR/M-R Manufacturers Near-term Construction

- Westinghouse eVinci (2027)
  - Heat Pipe technology
  - Up to 5MWe plus 8MWth residual heat
  - Nuclear demonstrator 2025
- Seaborg CMSR (2028)
  - Molten Salt technology
  - 200-800 MWe floating system
- GE Hitachi BWRX-300 (2028)
  - Boiling Water Reactor
  - 300 MWe
  - Ontario Power Generation (Darlington)
- NuScale Voygr (2029)
  - Pressurized Water Reactor
  - 77 MWe per unit, scalable from 4 to 12 units.
  - USNRC certified design for safety requirements
- ColdLead SEALER (Swedish Advanced Lead Reactor) (2030)
  - Molten Lead technology
  - SEALER-55 – 55 MW SMR, 25-year life cycle





Benefits of small modular reactors and Micro-reactors

Supporting the green shift *together* with renewables



Image: carnegieendowment.org

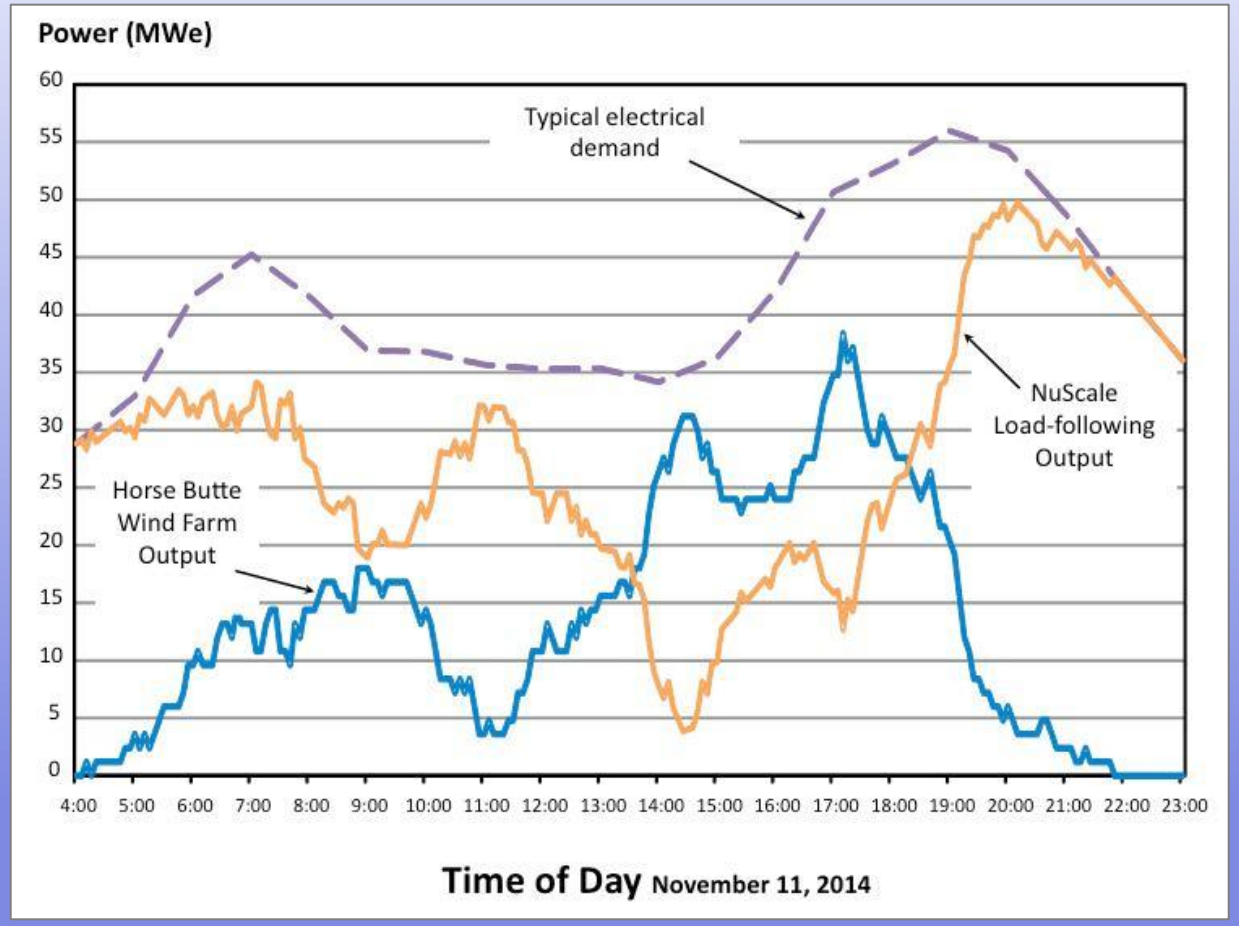


Image: Ingersoll, D. T., Colbert, C., Houghton, Z., Snuggerud, R., Gaston, J. W., & Empey, M. "Can Nuclear Power and Renewables Be Friends?"(2015)

Less space for more power

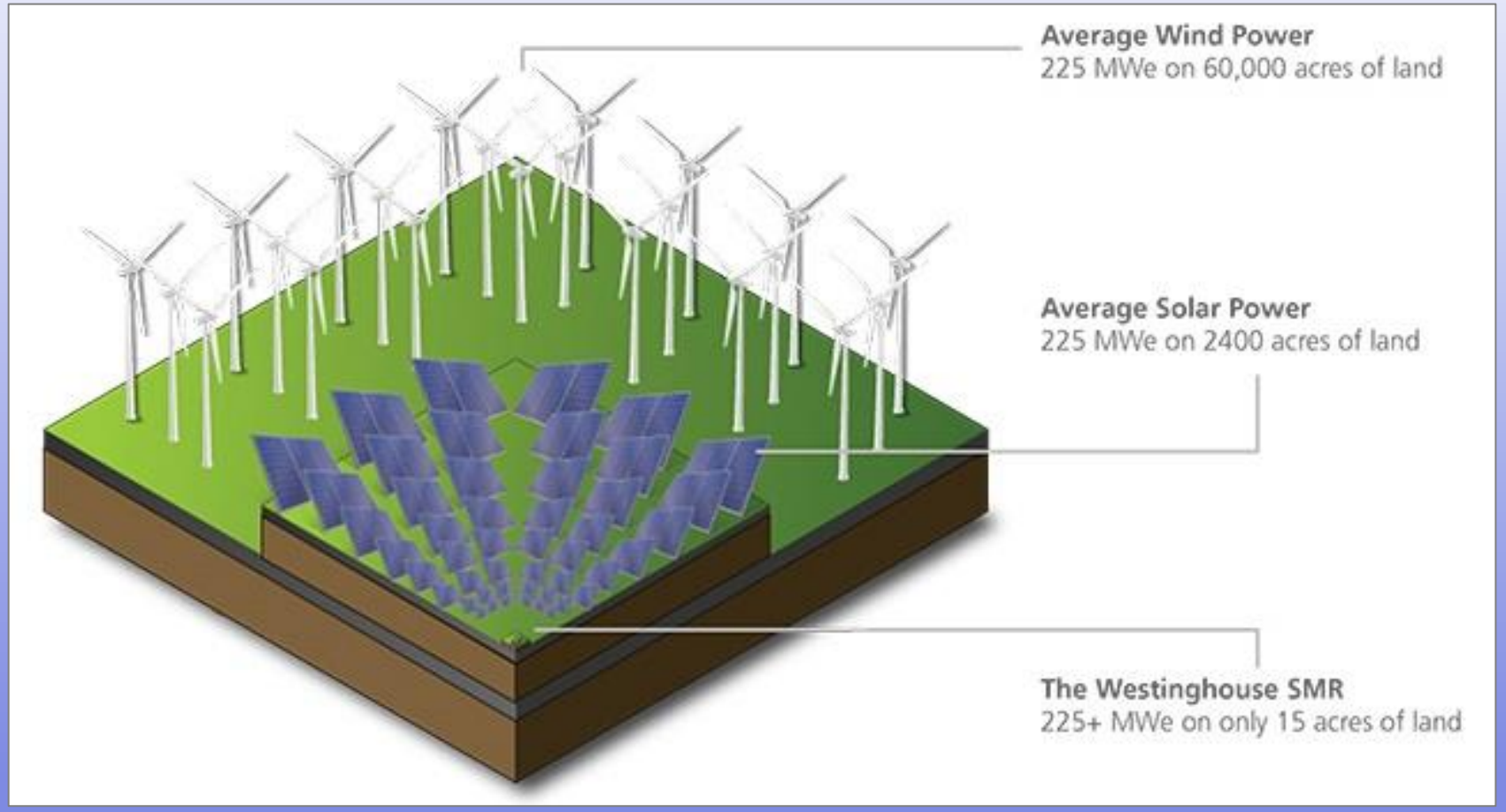


Image: www.westinghousenuclear.com

SMR design allows for more flexible deployment

- Significantly smaller footprint means that SMRs can be built in areas where it would not have been possible to construct a conventional nuclear plant.

- Recent uptake in exploration of how microreactors/SMRs could be used as sustainable alternative energy sources in situations where large amount of gaseous or liquid fuel is not desirable.

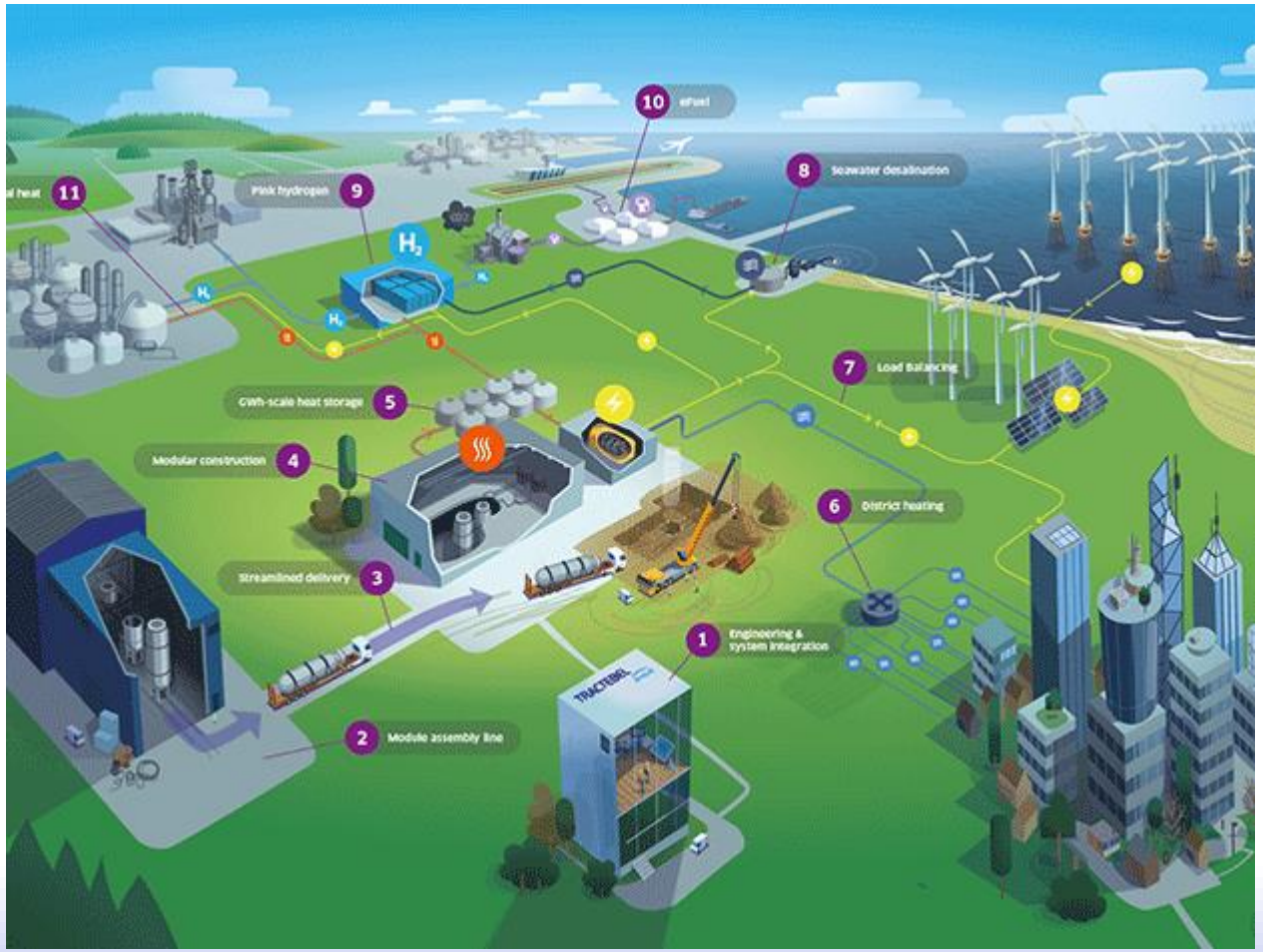
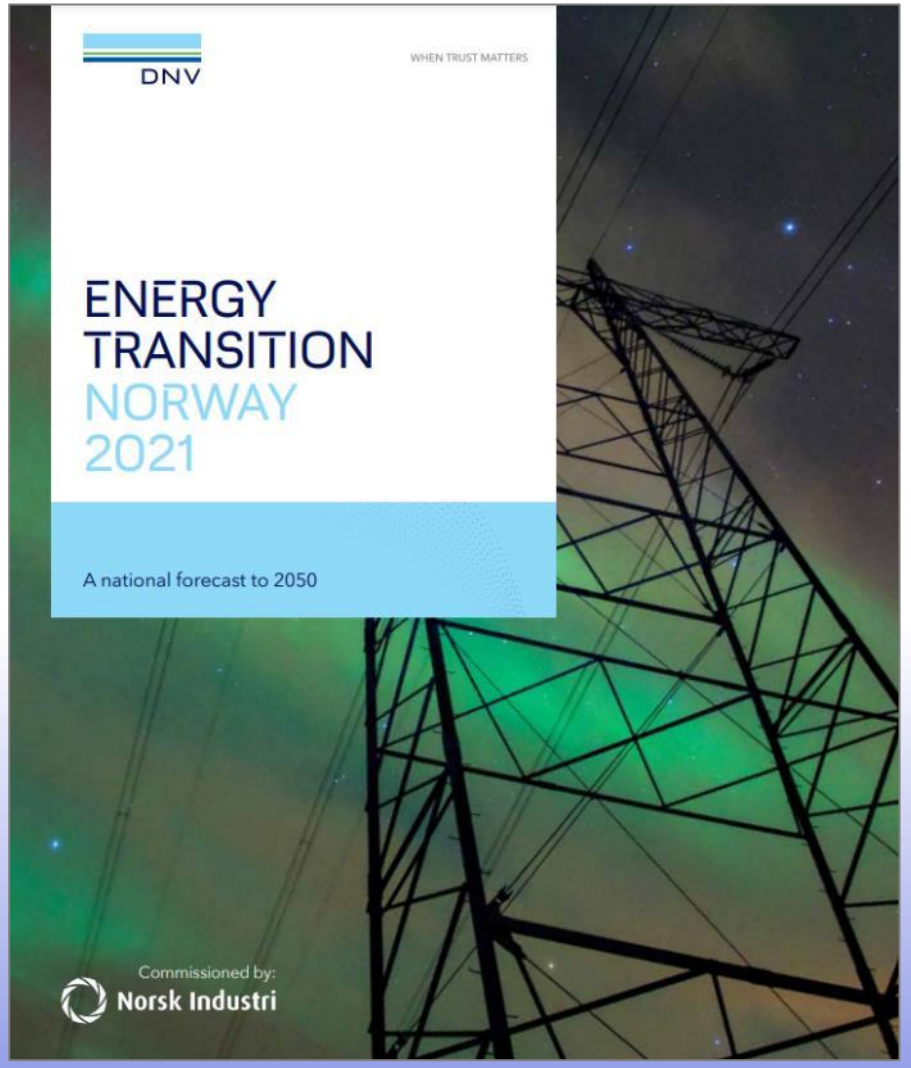


Image: tractebel-engie.com

Potential SMR use cases in Norway

The need for a stable electricity source

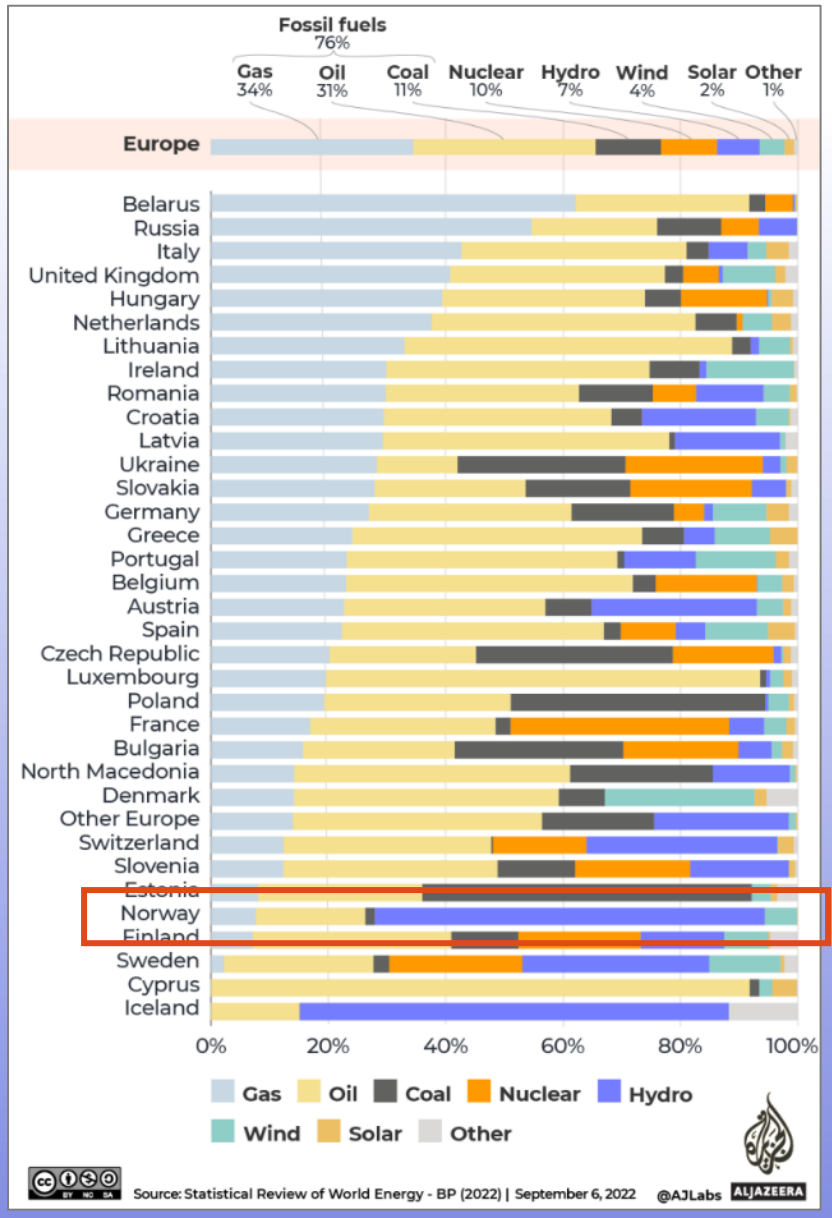
- The continued electrification of society will require stable, sustainable energy sources.
- Norway has set ambitious goals to reduce emissions by 55% by 2030 (compared to 1990 levels), and to reduce to 0% emissions by 2050.
- According to DNV's *Energy Transition Norway 2021* report, "Norway will most likely only achieve a 24% reduction by 2030 and a 79% reduction by 2050".
- In the meantime, demands for electricity continue to increase.



Why consider nuclear in Norway?

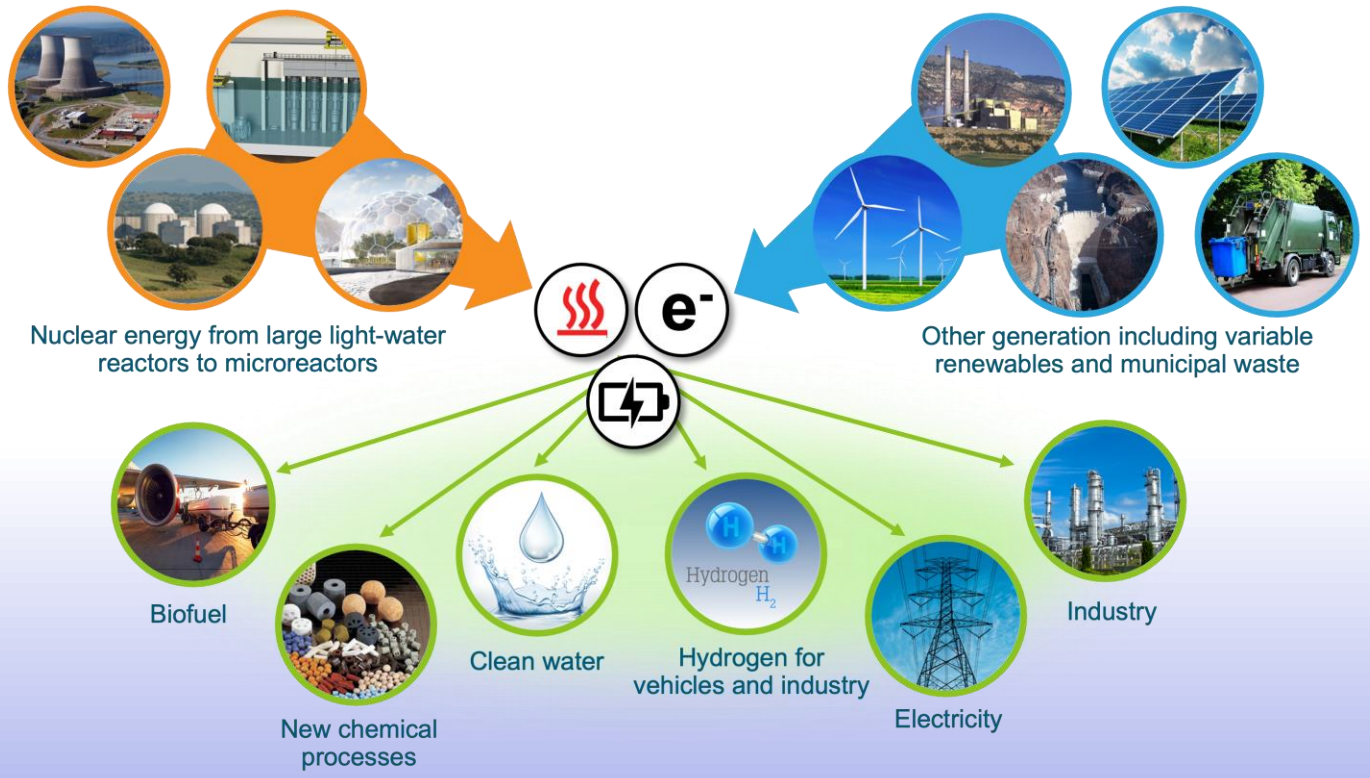
- Hydropower is still the primary electricity source in Norway today.
- Norway has invested a lot in hydrogen and battery technology in recent years. Nuclear can continue to support growth in these areas as a stabile power source.
- We are seeing a growing interest in utilizing nuclear in Norway in situations where it is either not feasible or not financially viable to replace fossil fuels with renewables, batteries or gaseous fuels.

Image: www.aljazeera.com



Potential use cases in Norway: Integration

- SMRs can be integrated with other energy systems to provide energy security and stability.
- The heat from SMRs can be used for co-generation of e.g. hydrogen for industry.
- The load-following ability of SMRs can be utilized in times of low production from our renewable sources.



Potential use cases in Norway: Remote locations

- The flexibility and significantly smaller footprint of SMRs means that they can be deployed in remote locations where it would not have been possible to build a conventional power plant.
- Norway's mountainous geography is no longer a barrier to clean, sustainable and stable energy.
- SMRs can provide energy security to remote locations, such as islands and rural areas not currently connected to the national grid.
- SMRs can be used for both district heating as well as providing baseload production.

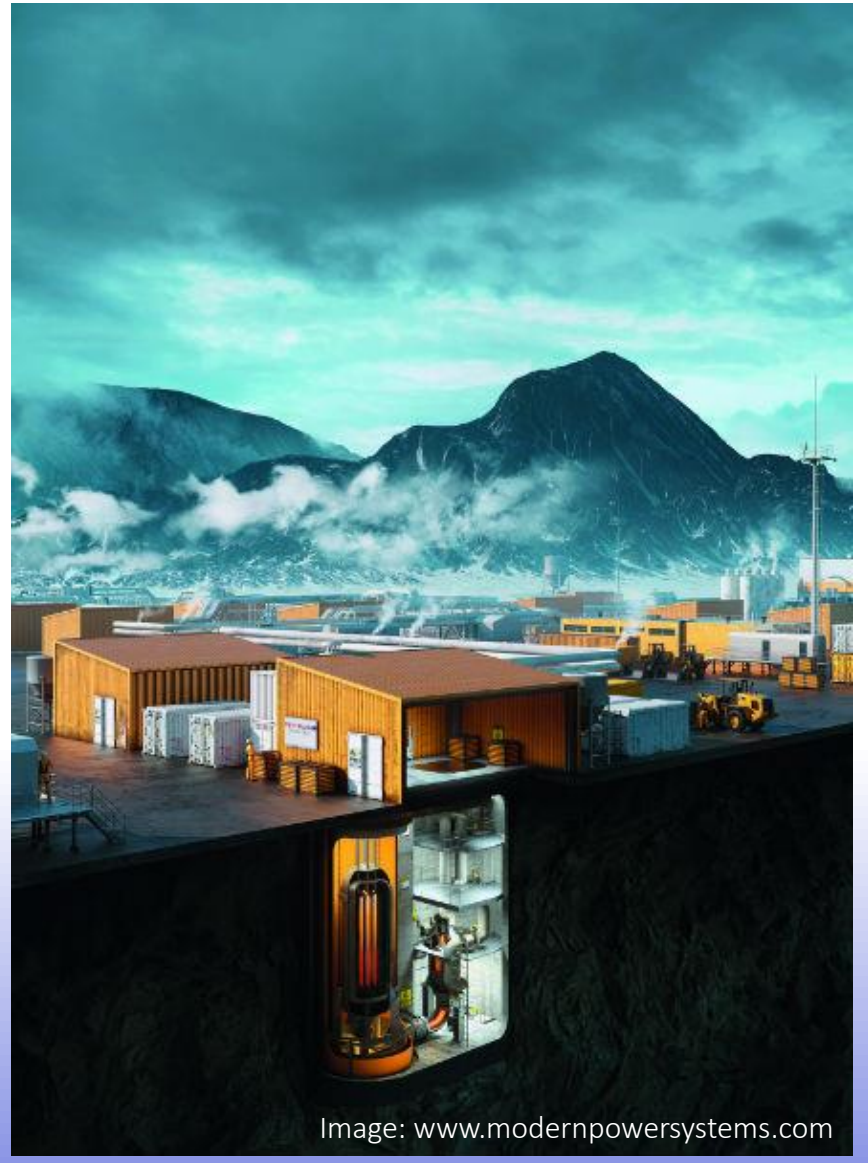


Image: www.modernpowersystems.com

Potential use cases in Norway: Local electrification

- The move towards electrification of society creates greater demands for stable electricity sources.
- SMRs can be deployed at local levels to provide electricity to discrete areas without needing to pull energy from the national grid.
- Examples include: airports, factories, and large-scale vehicle charging stations, such as distribution depots.

Image: meadhunt.com

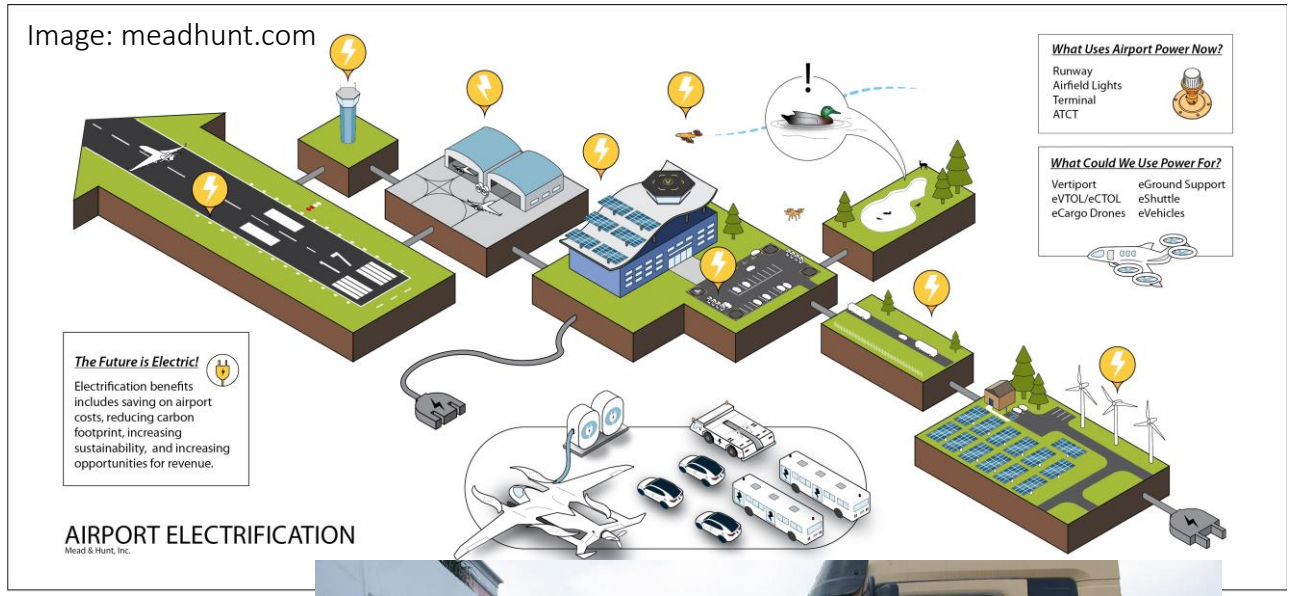


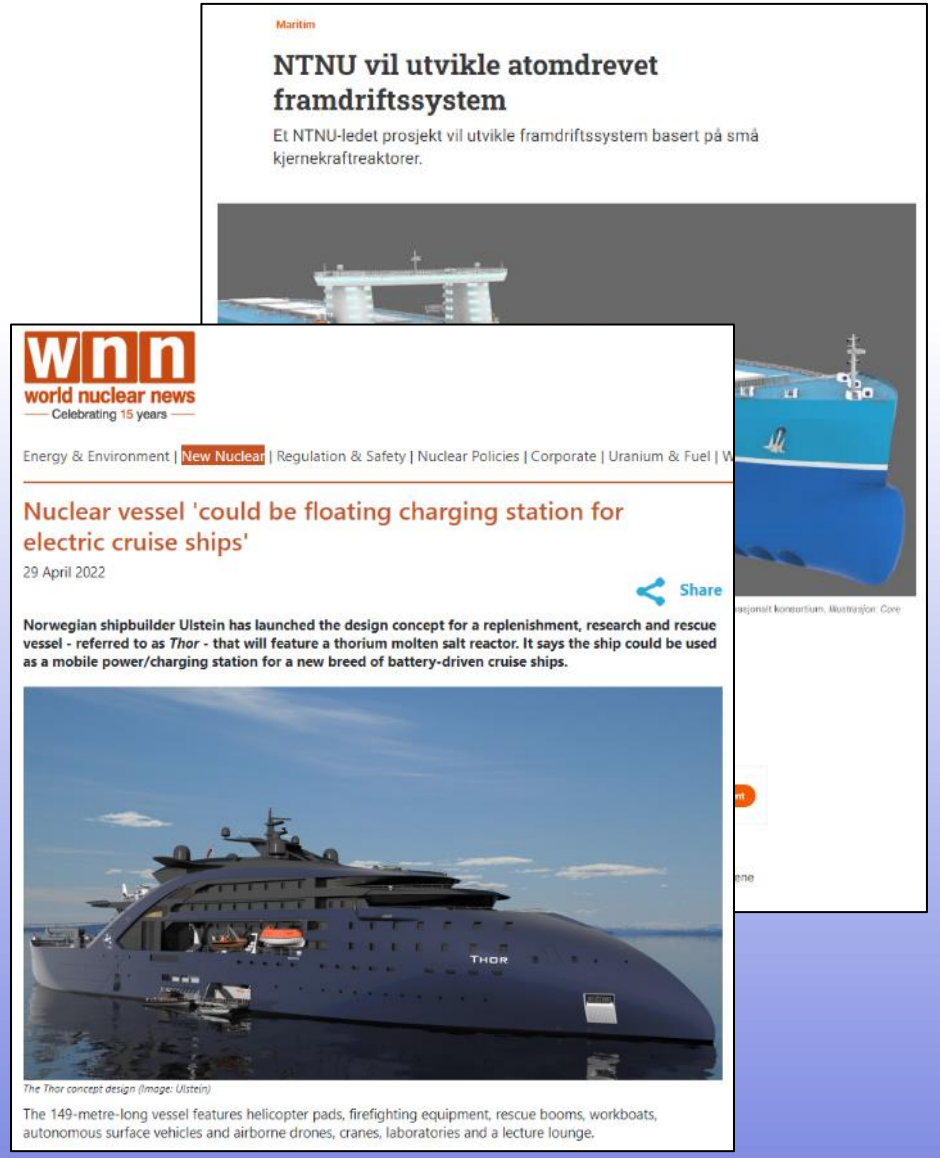


Image: www.en-plustech.com

Potential use cases in Norway: Maritime

- Already a lot of interest from the Norwegian maritime sector:
  - NTNU “NuProShip” project
  - Ulstein Thor concept

- Nuclear is a zero-emission alternative to highly polluting marine gas oil.
- Zero-emission alternatives such as hydrogen or ammonia take up a lot of valuable space on board due to high fuel density.
- This renders them infeasible for use on the longer-duration ocean trips typical of fishing, merchant ships etc.



Maritim

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Nuclear vessel 'could be floating charging station for electric cruise ships'

29 April 2022

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Norwegian shipbuilder Ulstein has launched the design concept for a replenishment, research and rescue vessel - referred to as *Thor* - that will feature a thorium molten salt reactor. It says the ship could be used as a mobile power/charging station for a new breed of battery-driven cruise ships.

The Thor concept design (Image: Ulstein)

The 149-metre-long vessel features helicopter pads, firefighting equipment, rescue booms, workboats, autonomous surface vehicles and airborne drones, cranes, laboratories and a lecture lounge.

Conclusions

- There is increasing need for Norway to be able to produce secure and stable electricity for national consumption.
- SMRs offer flexibility and integration opportunities that should be investigated as part of the energy mix for the future.
- There are several attractive use cases in the immediate future for SMRs in Norway.



Thank you!

Questions or inquires can be sent to
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