Nuclear and renewables can both support the climate change challenge

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Background

- Aim is carbon free energy system by 2050

- Fortum part of ongoing Finnish research project FLEX^e
  - Study of system that combines flexibility and smartness
  - Financed by Tekes
  - 18 industrial companies and 10 research organisations

- Our task is to explore the role of nuclear power in the future, flexible CO_2 free energy system

- I. First part was study made in 2014
  - Master's thesis "The role of nuclear power in the future energy system"
  - In this model nuclear power was modelled as base load
  - Showed that CO_2 free Nordic energy system is possible

- II. Second part 2015 →
  - Nuclear power as flexible element (nuclear participates in load following/grid balancing)
  - Technical limitations, possible new energy system model, value from flexibility…

I. Energy system model

Energy system model – what would a carbon neutral Nordic energy system look like in 2050?

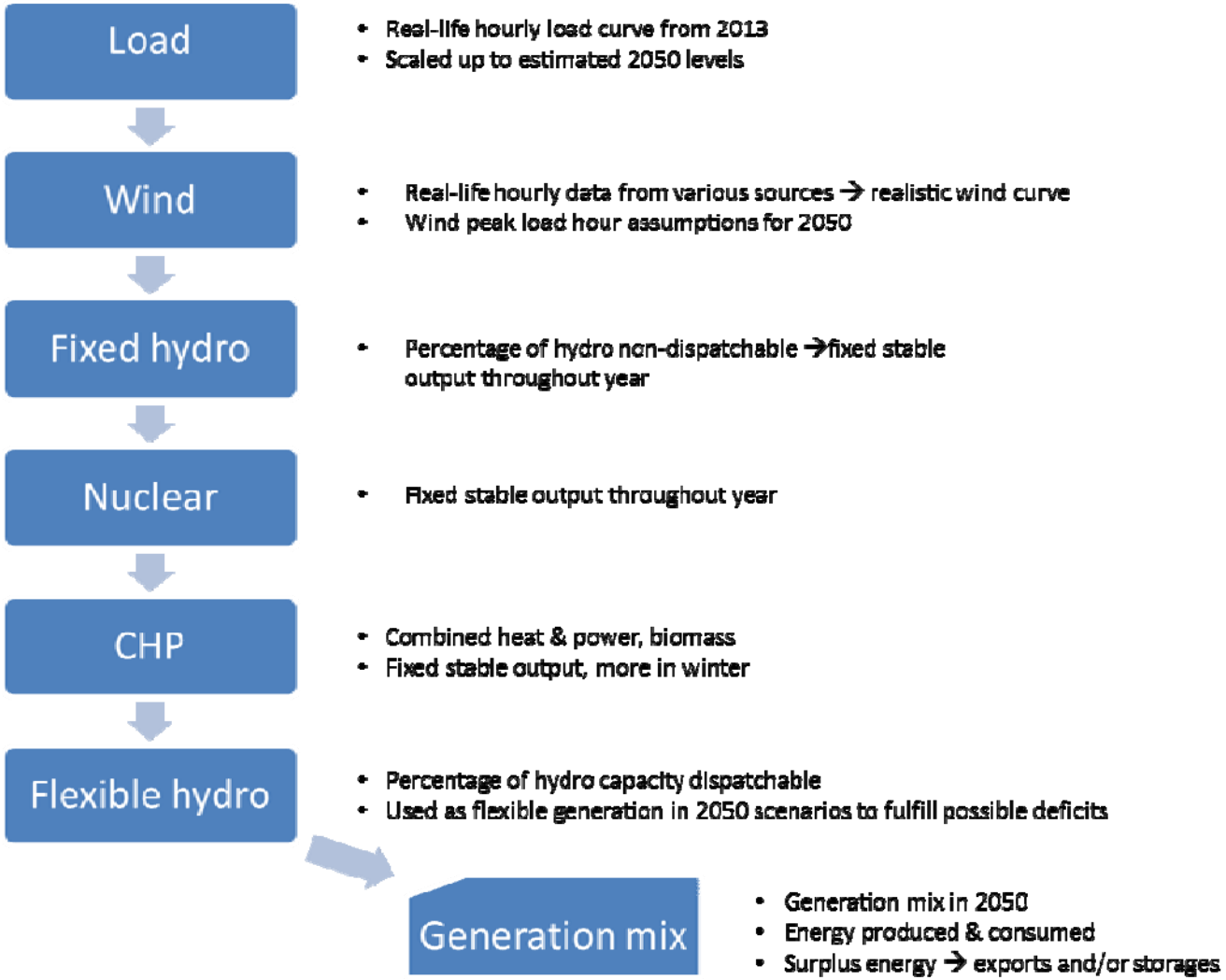
- Model uses real consumption/load data from 2013
  - Data from Nord Pool Spot
  - Finland, Sweden, Norway, Denmark
  - Scaled up to anticipated 2050 levels (IEA Nordic Energy Technology Perspectives, 2013)
  - 380 TWh in 2013 → 430-450 TWh in 2050

- Every hour of the year modelled
  - Hourly electricity consumption and generation in aforementioned countries

- Grid connections between countries considered to be more than adequate
  - Electricity grid considered as a single unit

- Model outputs:
  - Generation mix
  - Total energies (consumed/generated)
  - Hourly power balance in the system

Model logic



- Real-life hourly load curve from 2013
- Scaled up to estimated 2050 levels

- Real-life hourly data from various sources → realistic wind curve
- Wind peak load hour assumptions for 2050

- Percentage of hydro non-dispatchable →fixed stable output throughout year

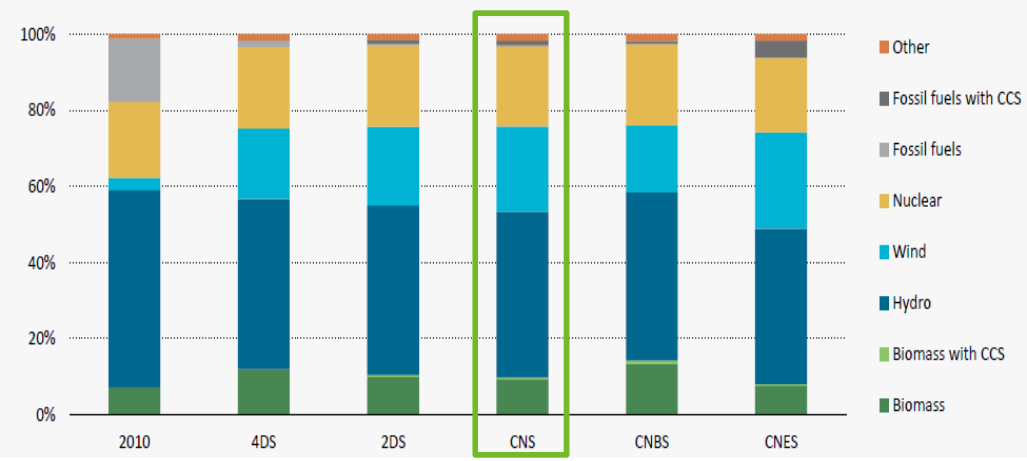
- Fixed stable output throughout year

- Combined heat & power, biomass
- Fixed stable output, more in winter

- Percentage of hydro capacity dispatchable
- Used as flexible generation in 2050 scenarios to fulfill possible deficits

- Generation mix in 2050
- Energy produced & consumed
- Surplus energy → exports and/or storages

Base scenario in 2050



- Installed capacities
  - Wind 40 GW (131 TWh)
  - Hydro 65 GW (193 TWh)
  - Nuclear 15,9 GW (122 TWh)
  - Biomass 12 GW (60 TWh)

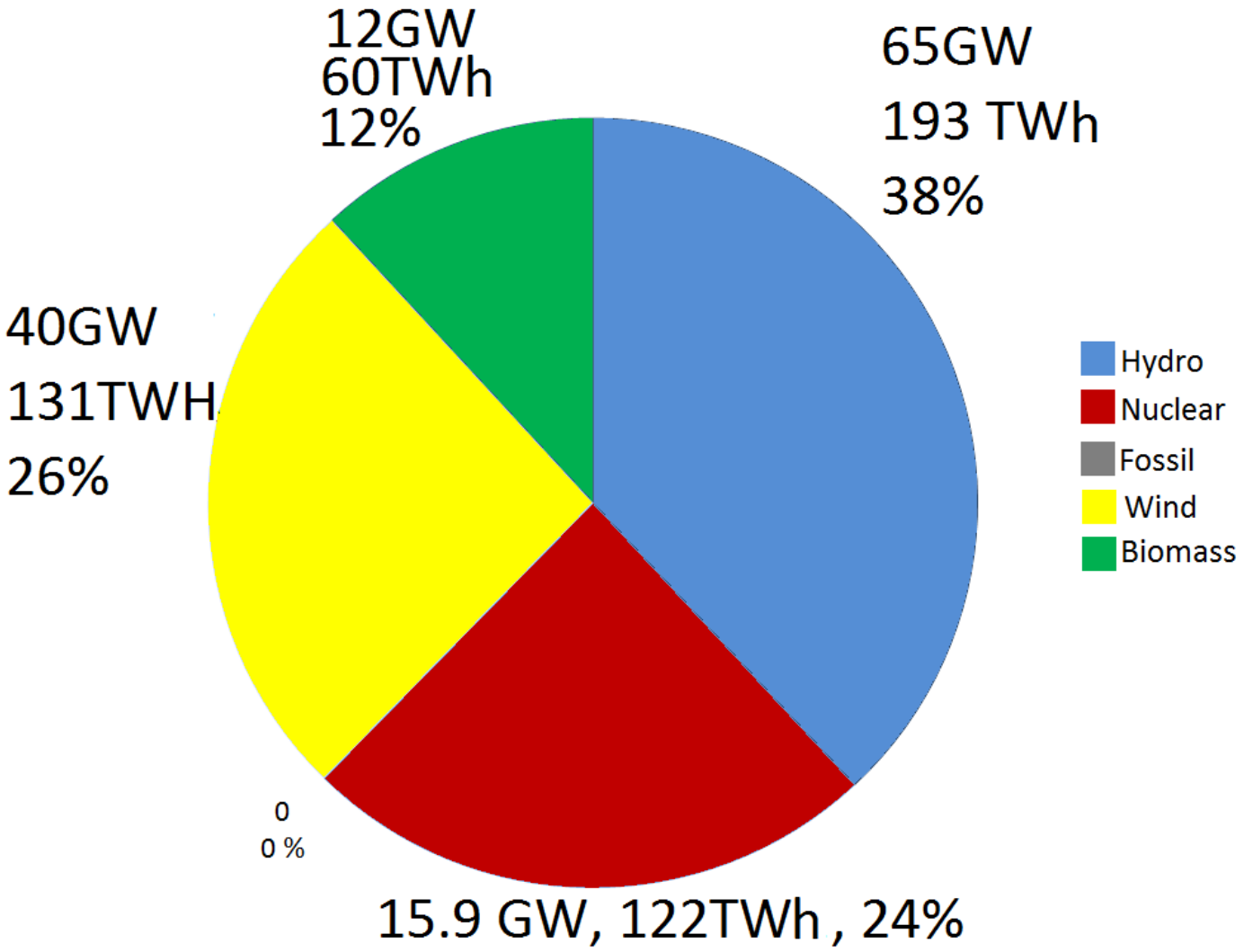
- Based on IEA's CNS scenario (Carbon Neutral Scenario)
  - except no fossil fuels

- Capacities from IEA's Nordic Energy Technology Perspectives (2013)
  - Nuclear in Sweden remains at the current level (~9,5 GW)*
  - Nuclear in Finland increases to 6,4 GW

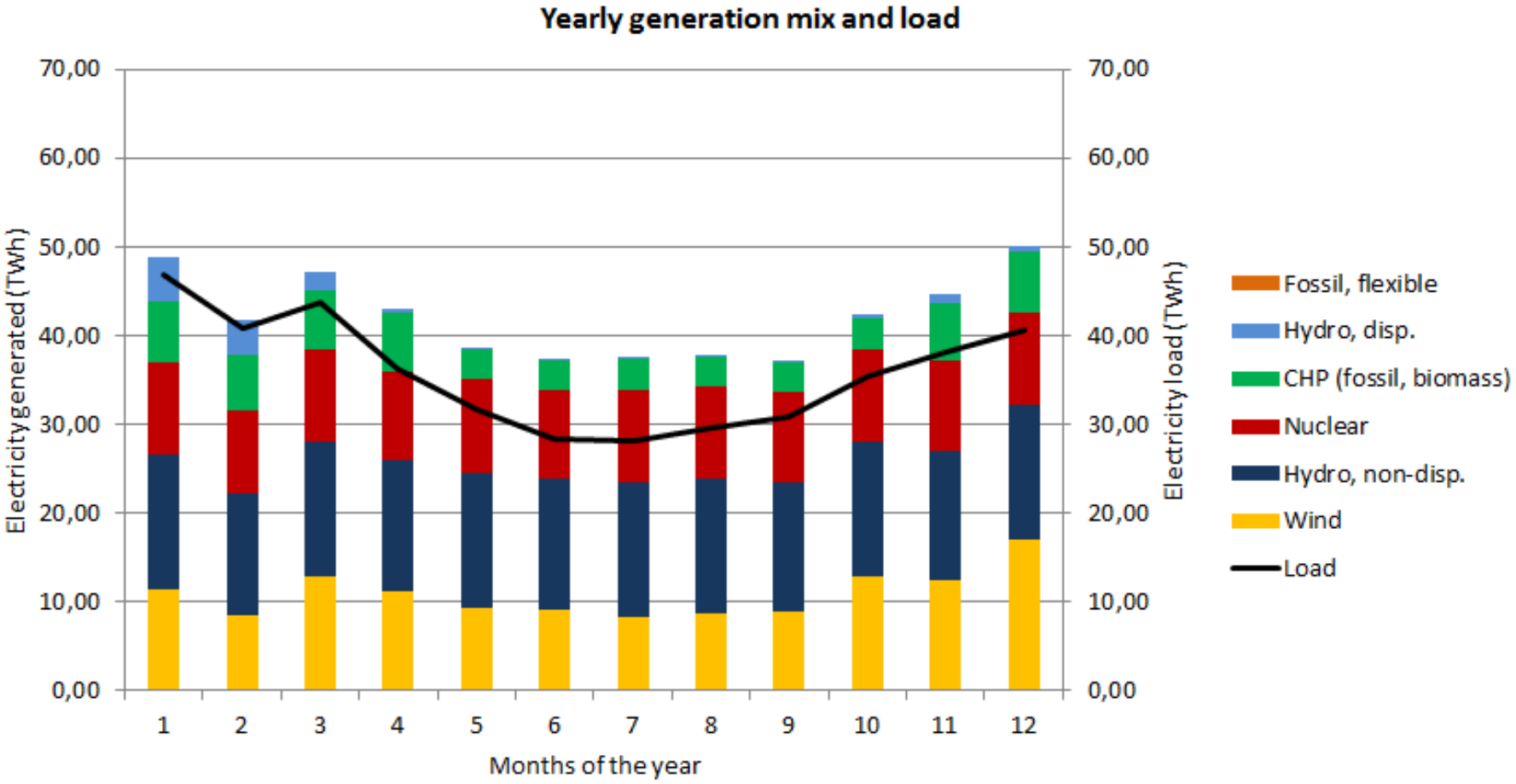
*unlikely due to premature closures of OKG 1&2 and Ringhals 1&2

- Total generated energy: 506 TWh
- Consumed: 430 TWh
- Nordic countries will become net exporters of energy in 2050
  - IEA assumption, also in this study

Generation mix in Base scenario (2050)



The generation mix and load month to month in the Base scenario



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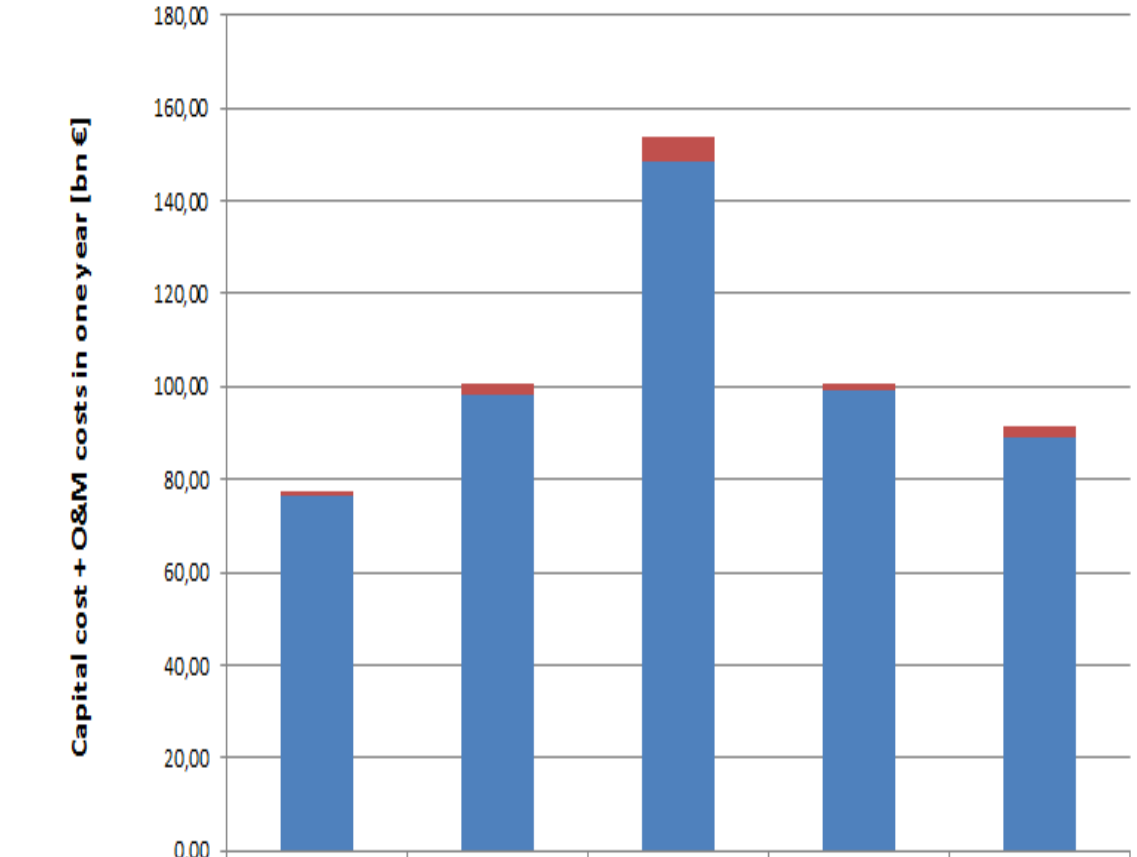
And what if no nuclear?

- In the Base scenario, quarter of electricity generation from nuclear
  - Other CO_2 free or carbon neutral generation sources to replace nuclear
- Overnight costs* for nuclear, wind and biomass
  - Data from U.S Energy Information Administration (2013)
  - Same amount of generated energy in the picture



	15.9 GW of Nuclear	15 GW of Wind + 14 GW of Biomass BFB	15 GW of Wind + 14 GW of Biomass CC	33 GW of Wind	24.5 GW of Biomass BFB
Total O&M cost [bn. €]	1,29	1,98	5,08	1,43	2,29
Total capital cost [bn.€]	76,36	98,42	148,68	99,13	89,00

Each graph has about the same amount of generated energy

* The term ”overnight” refers to the cost of the projects as if no interest were incurred during its construction. (ie. the project was completed ”overnight”)

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Base scenario summary

- Traditionally nuclear power is run as base load generation
  - Also in this study
  - High fixed costs and low variable costs
    - more efficient to operate the plant constantly at rated power instead of on part loads
  - Predictable, reliable generation
  - Ensures self sufficient energy system

- Studied energy system had large share of hydropower
  - Works as the major balancing element
  - Hydropower capacity is enough to handle the balancing needs of the grid
    - assuming that large share of nuclear provides base load

- Energy system had enough generating capacity to handle also zero wind hours
  - zero wind hours unlikely due

II. Ongoing and future research

We know that…

- High share of renewables are penetrating markets
  - Solar and wind have fluctuating nature

- At the moment, grid balancing in Nordic is handled with hydropower and fossil fuelled power
  - Aim is to reduce carbon emissions from electricity sector → replace fossil fuelled (flexible) generation
    - Nuclear power?
      - Large-scale carbon free load-follow generation
    - Energy storages?
      - Under research, pumped hydro storages (PHS) and compressed air energy storages (CAES) the most promising
    - Biomass?
      - Carbon neutral

Next steps in our research

- A new energy system model will be made
  - Includes wind + solar + hydro + nuclear
  - Nuclear participates in grid balancing
  - More accurate modelling of new renewables, including higher share of solar power
  - Possibly Demand Side Management (DSM)

- Technical aspects of load following with nuclear power plant
  - Many studies already exist which show that load following is possible
    - experiences from France and Germany, Elforsk reports from 2011-2012
  - Boundary conditions for model
    - ie. ramp rates

- How the generation profiles of wind, solar and nuclear fit together
  - Wind and solar produce more electricity during summer
  - How well nuclear power can react to changes in generation and consumption levels
    - pre planned load following?

The load following ability of different power plants

Technology	Start-up time	Maximal change in 30 sec	Maximum ramp rate [%/min]	Maximum ramp rate [MW/min]
Open cycle gas turbine plant (200 MW)	10-20 min	20-30 %	20	40
Combined cycle gas turbine plant (500 MW)	30-60 min	10-20 %	5-10	25-50
Coal plant (600 MW)	1-10 hours	5-10 %	1-5	6-30
Nuclear power plant (1 200 MW)	2 hours - 2 days	up to 5 %	1-5	12-60

Value creation of nuclear in the future

- Future energy market will probably look different

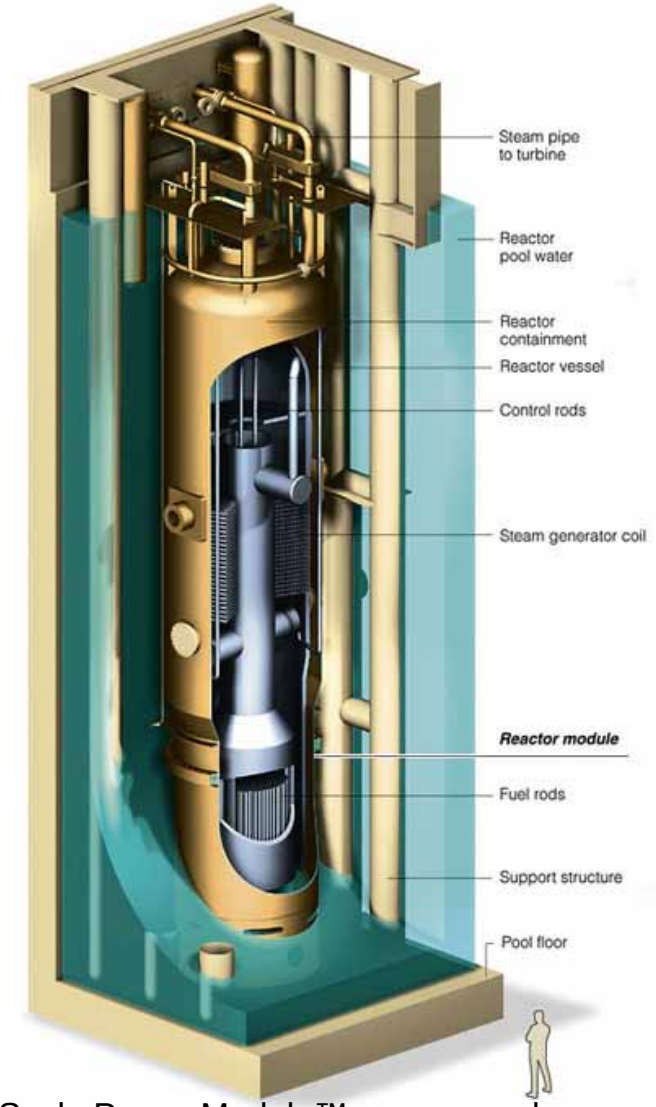
- Nuclear power can offer other products than simple base load
  - Capacity market?
  - Value from inertia
  - Flexibility
  - Heat

- Share of intermittent renewables increases → need for flexibility and reliability in the power system will increase
  - How will flexibility be valued in the future market?
  - Load follow capability could provide more revenue

Big units vs. small

- Largest power generating unit in the Nordic system will be Olkiluoto 3
  - 1600 MWe
  - Poses challenges for electric grid
  - Time between investment decision and grid connection is long (even 15 years)

- Small modular reactors (<300 MWe)
  - May be more attractive than larger units in the future
  - Harmonized licensing and factory fabrication reduce costs
  - Shorter construction times (~ 3 years)
  - Smaller unit sizes are better for grid management



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Other possible components of future energy system

- Smart grid
  - Better supply and demand side management
  - Provides consumers with greater information and choice of supply
  - Facilitates the better connection and operation of generators of all sizes and technologies

- Energy storages
  - Large-scale thermal storages are already competitive for answering heating and cooling demands in many regions
  - Electricity storages
  - Heat storages

- Nuclear cogeneration (heat & electricity)
  - Already used in some countries (Switzerland, Russia)

Summary

- Part I
  - CO_2 free Nordic energy system is possible with IEA assumptions and generation mix
  - Nuclear power as base load and hydropower solely responsible for balancing

- Part II
  - Intermittent renewables will define the future energy system
    - flexibility and reliability will be highlighted in the future
  - New role for nuclear power
    - load following
    - new value from flexibility, inertia, heat…?

- We believe that nuclear and renewables can both be part of CO_2 free future

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