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Small Reactor Economics

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Insight in Economics™

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Small reactors are a market response to issues with large LWRs

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- Large light water reactors
  - Large total capital cost; difficult to fund
  - Large increment of nuclear capacity
  - Hard to fit into small electricity systems
  - Long time to develop and construct
  - Significant business risk
  - Potential reactor safety issues
- Small reactors may offer solutions

Three topics

1. **Why small reactors are likely to have higher costs**

2. **Proposed small reactor approaches that may reduce costs**

3. **Added value from small reactors that may offset higher costs**

How topics related to small reactor costs

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1. Small reactor cost higher
- loss of scale economies
- FOAK issues

2. Small reactors cost reduction
- Simpler design
- Shorter build time
- Multiple modules
- Factory build

Gen II large LWR costs (€/kWe)

Small reactor costs (€/kWe)

3. Increased value
- Safety
- Planning
- Other

1 - Small reactor cost higher
What is large LWR benchmark?

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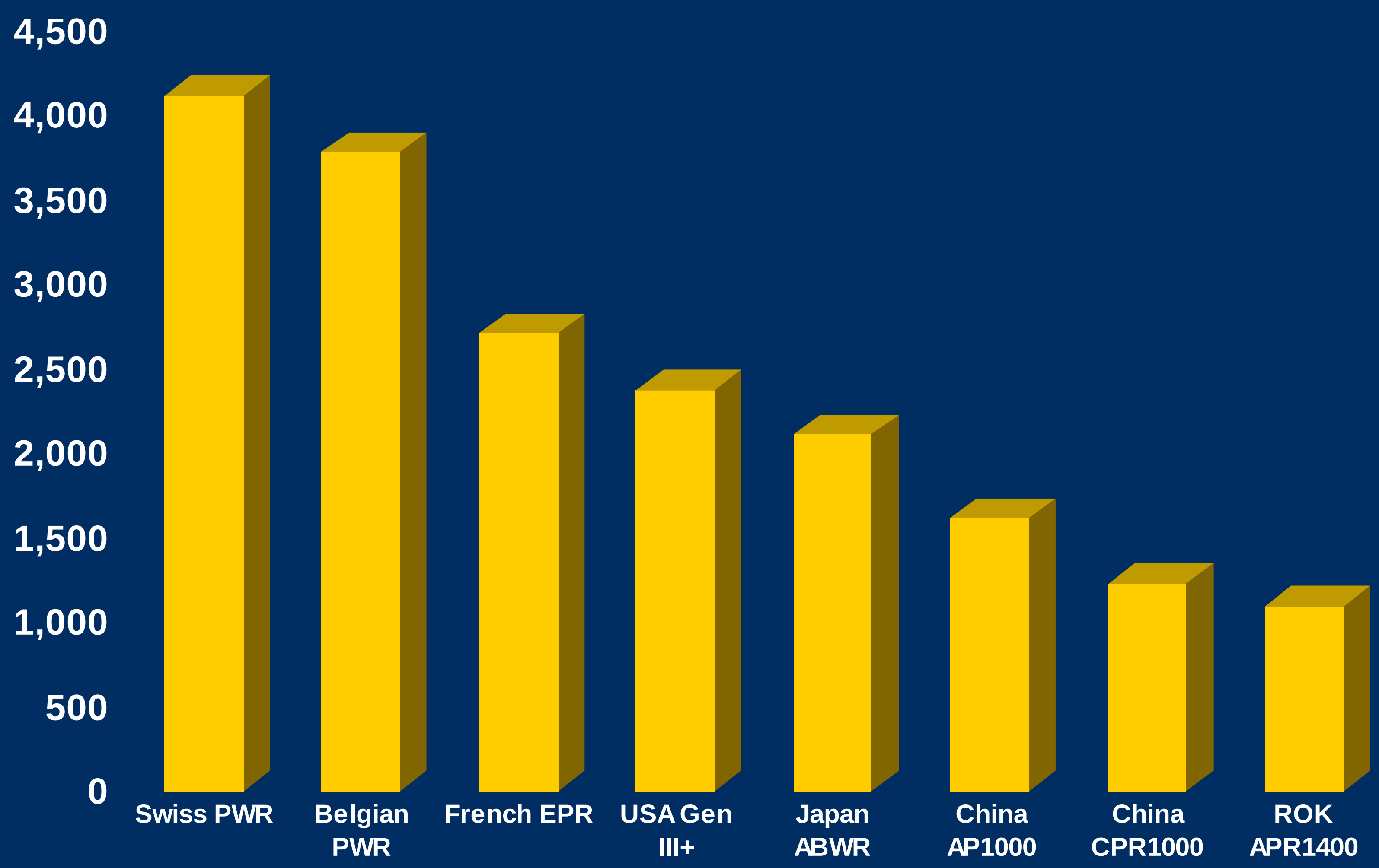

Source: OECD 2010, Table 3.7a, overnight capital costs in €//kWe (1.4244 USD/Euro)

1 - Small reactor cost higher
Economies of scale

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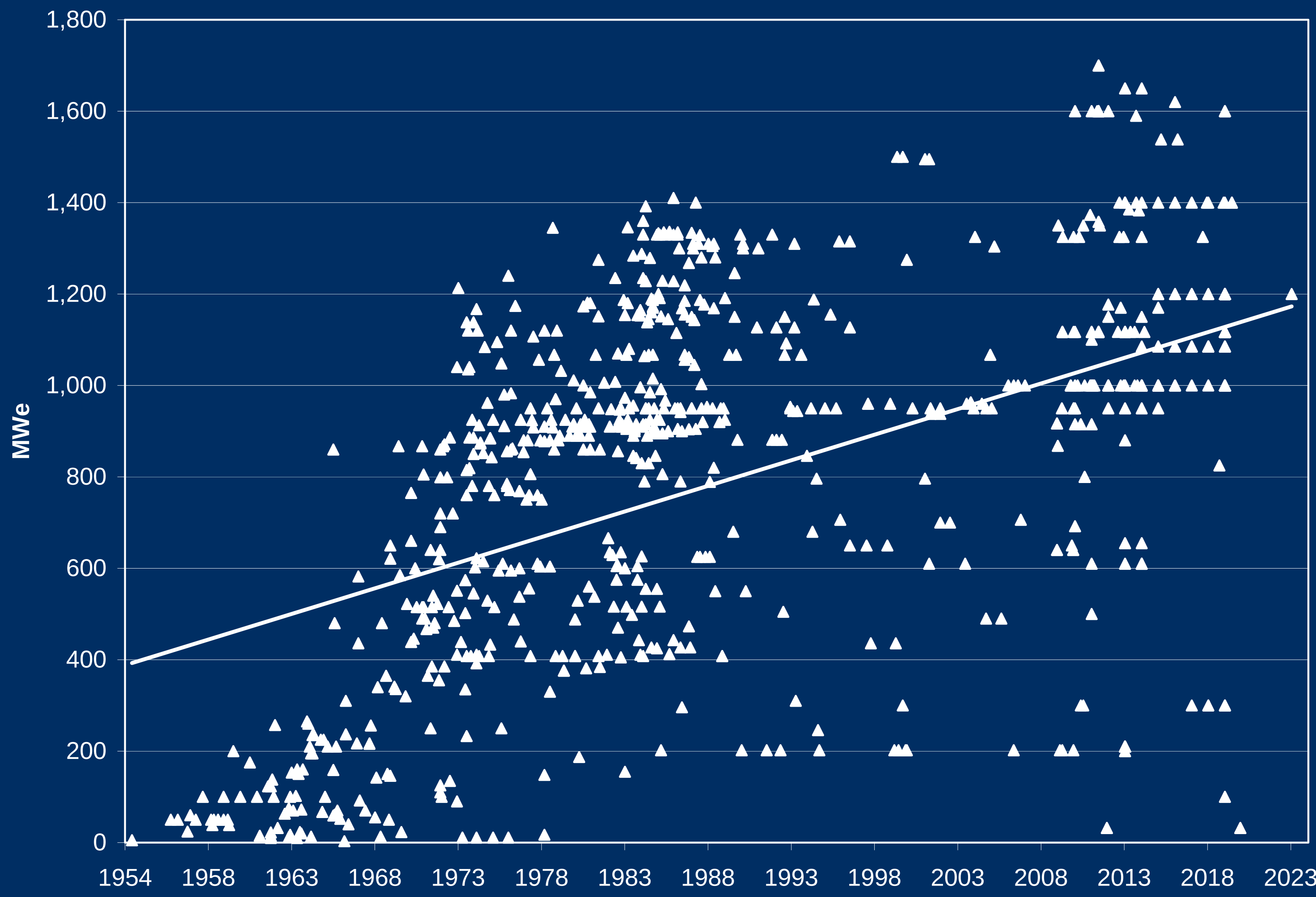
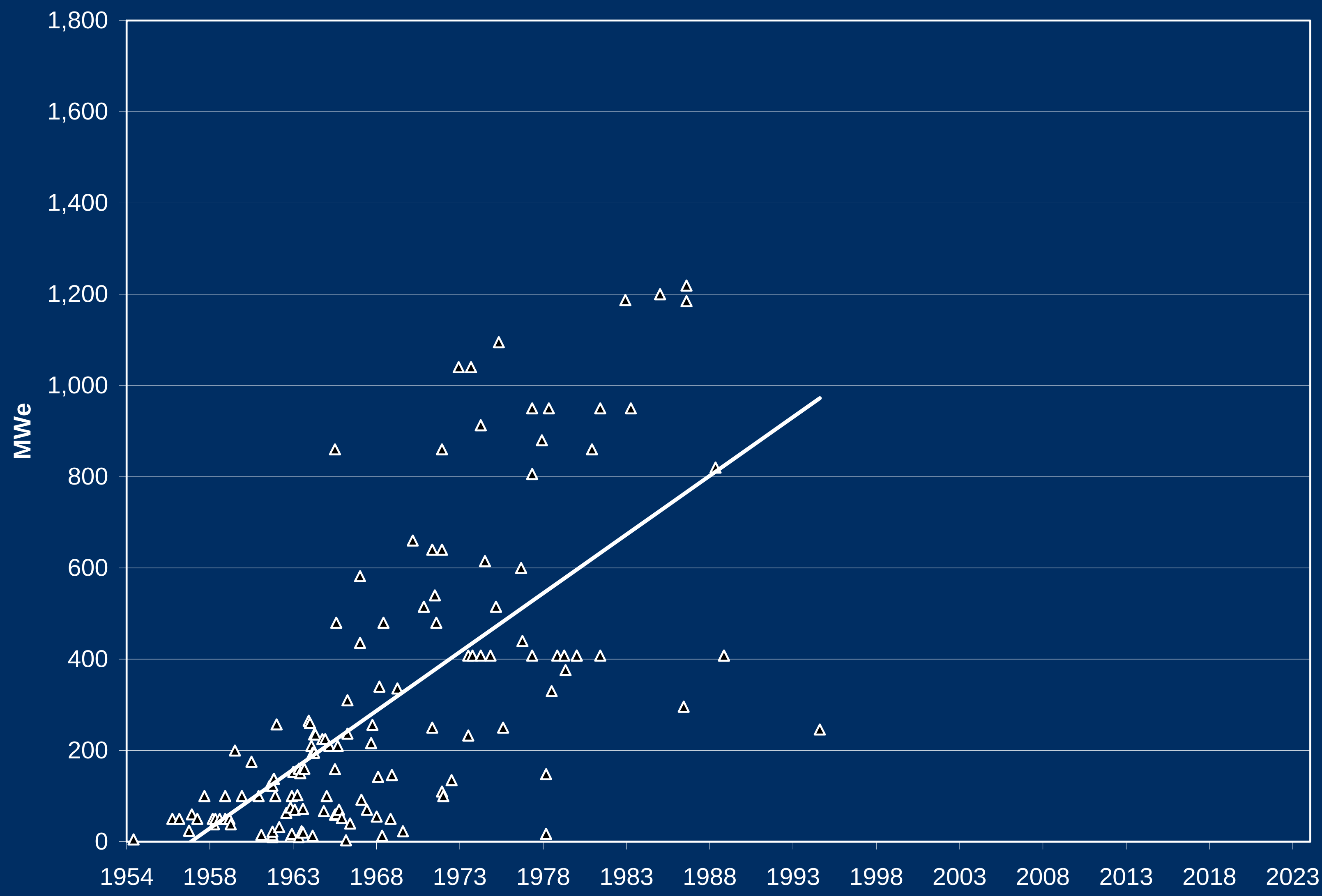
- Trend in nuclear power plants toward larger units is driven by scale economies
- Economies of scale apply strongly to nuclear power plants:
  - Significant costs (e.g., seismic studies, site acquisition, environmental assessment, nuclear license process) vary little with plant size;
  - Components exhibit physical economies of scale (buildings, containment, piping systems, reactor pressure vessels)
  - Non-fuel operating costs (e.g., staff) not tightly linked to plant size
- Scale economies mean that a larger nuclear power plant will achieve lower costs per unit of electricity produced

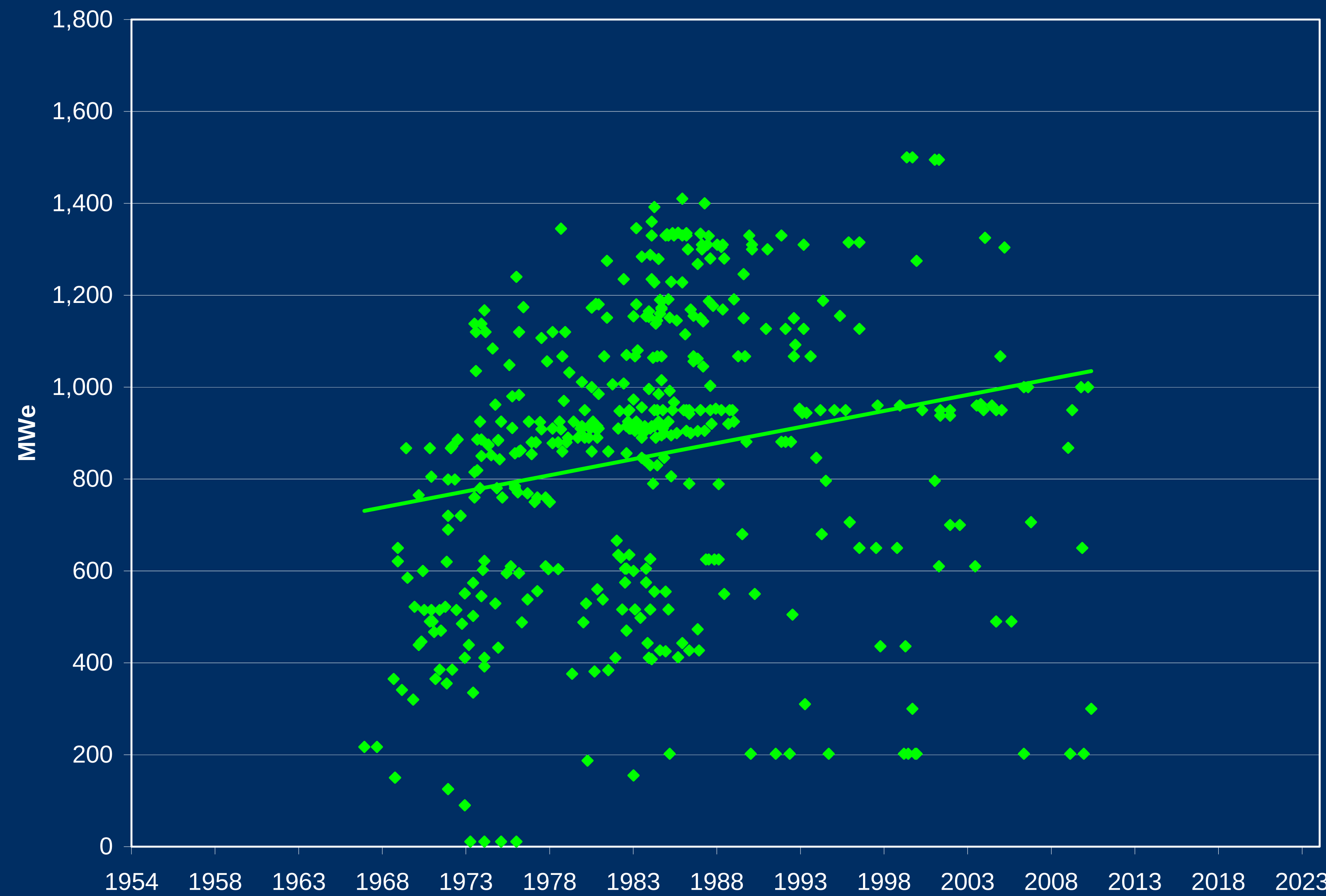
1 - Small reactor cost higher
Economies of scale - all nuclear plants



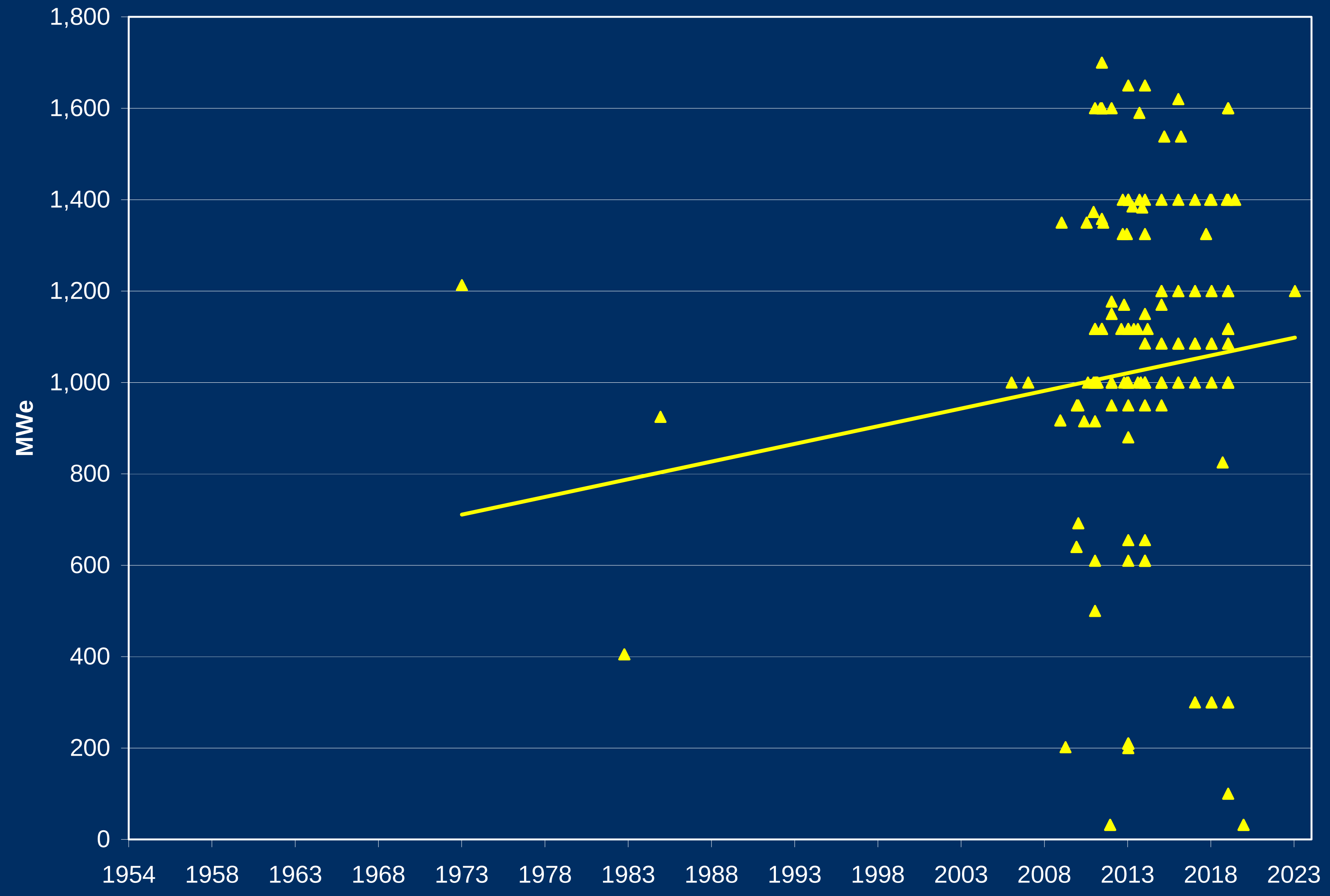
1 - Small reactor cost higher
Economies of scale - closed nuclear units



1 - Small reactor cost higher
Economies of scale - operating nuclear units



1 - Small reactor cost higher
Economies of scale – nuclear units under construction and planned



1 - Small reactor cost higher
Economies of scale - Moore's Law does not apply to nuclear!

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- Moore's law
  - applies to information, specifically to the number of transistors that will fit onto silicon chips
  - puts more capability into smaller and cheaper electronic devices (e.g., consumer electronics)
- Why not nuclear power plants?
  - Moore's law does not apply to power generation
  - Large amounts of power involves large power plants and large transmission wires
  - In electricity industry, higher thermal efficiency, lower capital costs come from increases in size to benefit from scale economies and other factors

1 - Small reactor cost higher
Economies of scale – Project issues

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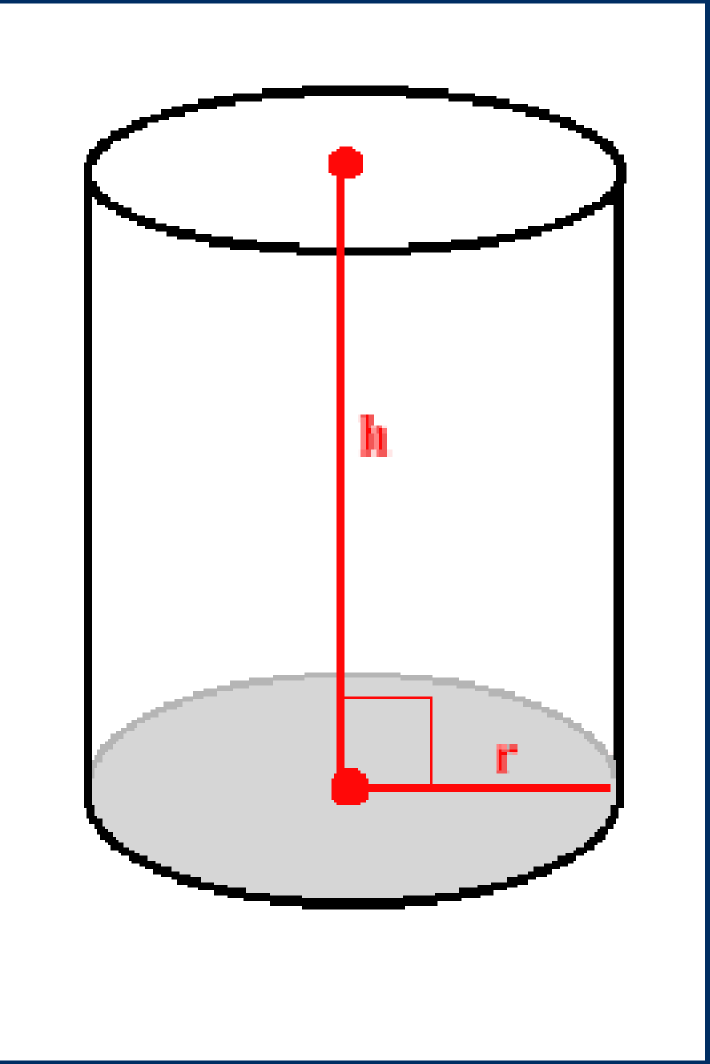
- Cost to develop and license a new reactor design may be more than €300 million – regardless of the MWe size of the new reactor
- Innovative and alternative reactor designs (e.g., integral PWR, metal-cooled, HTGR, etc.) may involve even greater costs to license, because nuclear safety regulations (and regulators) focused on conventional LWR designs
- Project site/environmental assessment may cost the same regardless of reactor size

Similar project costs + fewer MWe = higher MWh costs

1 - Small reactor cost higher
Economies of scale - physical realities

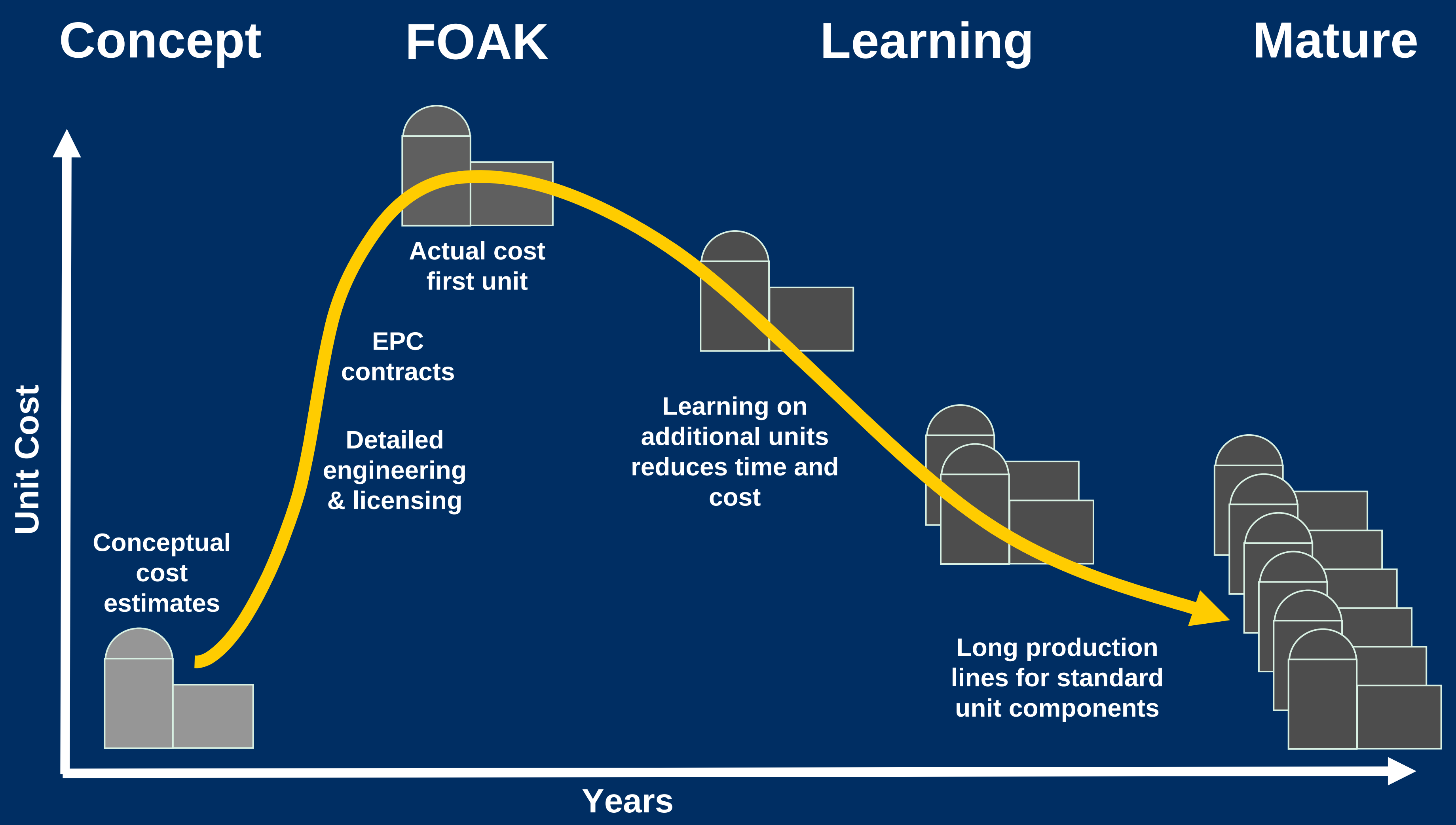
Right cylinder:

- Reactor pressure vessel, pipes
  - Volume = $\pi * r^2 * h$
  - Wall area = $2 * \pi * r * h$
- For same wall thickness and height, doubling the radius =
  - 4 (2^2) times increase in volume
  - 2 times increase in materials cost



Smaller size means higher cost

1 - Small reactor cost higher
Small reactor designs in pre-FOAK phase



1 - Small reactor cost higher
Small reactors - new ***industry*** learning curve

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- Large LWR nuclear designs have decades of operating experience across multiple countries
- Operating and regulatory approaches evolved over time
  - Lessons from experience/incidents/accidents
  - Wide sharing of lessons (Regulators / INPO / WANO / IAEA / User groups)
- Design improvements based on experience
  - Better materials of construction
  - Prevent long-term failures (e.g., steam generators)
  - Fuel design and manufacture
  - Man-machine interface / I&C
  - Safety concepts, systems, and equipment

2 - Small reactor cost reduction

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- Simpler designs may lower cost – fewer components, etc.
- Shorter construction time
- Mass production with large numbers of units - accelerated learning, shared infrastructure, upstream component suppliers with large orders
- Some designs have longer fuel cycle that may lower fuel cost
- Intrinsic safety may mean lower construction cost

2 - Small reactor potential benefits
Safety features may lower costs

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- Enhanced safety may mean small reactor designs can be licensed with lower containment & safety equipment cost
- Elimination of accident initiators (e.g., no large-break loss-of-coolant-accident in integral PWR designs)
- Reduced source term may allow smaller site radius, smaller emergency planning zone, etc.
- Improved passive decay heat removal from reactor vessel may allow designs with fewer/no active safety systems
- Intrinsic safety (e.g., HTGR designs) may mean a much simpler (and less costly) approach to containment

2 - Small reactor potential benefits
Fabrication and construction benefits

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- Physically smaller components
  - Eliminate or reduce number of large forgings needed
  - Typical large PWR requires more than 10 large forgings; many SMRs require none
- In-factory fabrication; less on-site activity
  - Reduces schedule uncertainty & cost
  - May mean higher quality control
- Below-grade construction
  - Improve resistance to external events and sabotage without need for elaborate and costly structures
  - More opportunities for gravity feed emergency cooling

3 - Small reactor added value
Features may support higher unit cost

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- Small size – fit with smaller utilities / countries
- More options for site selection
  - Reduced size of site & emergency planning zone (EPZ)
  - Use of seismic isolators allows wider range of sites
  - Lower water usage
  - Easier transport to wider range of sites
- Grid stability
  - Closer match to traditional power generators
  - Smaller fraction of total grid capacity
- Demand growth & planning - ability to add (and pay for) capacity as demand grows

3 - Small reactor added value
Financial & project value

- Total project cost lower
  - Improves financing options
  - Lower financing cost / interest during construction
  - Lower and more predictable cash outlay;
- Faster and more certain time from start to revenue
- Smaller nuclear units with dispersed locations
  - Lower cost for transmission system upgrades
  - Lower single shaft risk & reserve requirements
- Higher safety & lower accident probability / consequence - additional value perceived post-Fukushima
  - Preference for smaller, dispersed, intrinsically safe reactors
- May be more resistant to proliferation issues

Conclusions

- Cost of small reactors still unknown
- Uncertain if private/commercial companies can take these reactor designs to market – long time, large cost
- It is hard enough to get a large LWR project to completion, new small reactor designs pose even more risk – maybe relatively small total investment will help
- Regulators may be a problem (i.e., hard to shift from large LWR paradigms)

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