International Atomic Energy Agency

Approaches to Assess Competitiveness of Small and Medium Sized Reactors

(Paper 1S01)

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CONTENT

Definitions/ Developments in Member States

Small Reactor: < 300 MW(e)
Medium Sized Reactor: <700 MW(e)

- **This year, of the 436 NPPs operated worldwide 134 are with SMRs; of the 45 NPPs under construction 10 are with SMRs**
- **In 2009, not less than 45 concepts and designs of advanced Small and Medium Sized Reactors (SMRs) are analyzed or developed in** *Argentina, China, India, Japan, the Republic of Korea, Russian Federation, South Africa, USA, and several other IAEA member states*

SMRs - Options for Near-Term Deployment

Reactors with Conventional Refuelling Schemes

PWRs with integrated design of primary circuit

- **IRIS - Westinghouse (USA) + Intl. Team**
- **CAREM – CNEA, Argentina**
- **SMART – KAERI, the Republic of Korea, and several others**

PWRs – marine reactor derivatives

- **KLT-40S *(Floating NPP)* – Rosenergoatom, Russia**
- **VBER-300 *(Land based NPP)* – OKBM + Government of Kazakhstan, Rosatom**

Advanced Light Boiling Water Cooled Heavy Water Moderated Reactors, Pressure Tube Vertical Type

- **AHWR (Designed specifically for *U233-Pu-Th fuel*) – BARC, India**

High Temperature Gas Cooled Reactors

- **HTR-PM – INET, China**
- **PBMR – PBMR Pty, Ltd., South Africa**

Small Reactors without On-site Refuelling

- **ABV *(Floating NPP)* – OKBM, Russia; *NuScale - NuScale, USA***

Project "Common Technologies and Issues for SMRs"

P&B 2008-2009: 1.1.5.4 Recurrent Project, Ranking 1

Objective:

➢ To facilitate the development of key enabling technologies and the resolution of enabling infrastructure issues common to future SMRs of various types

Expected outcome:

➢ Increased international cooperation for the development of key enabling technologies and the resolution of enabling infrastructure issues common to future SMRs of various types

What could be done to support advanced SMR deployment?

- ➢*Adjust regulatory rules toward technology neutral and risk-informed approach*
- ➢*Quantify reliability of passive safety systems*
- ➢*Justify reduced or eliminated EPZ (proximity to the users)*
- ➢*Justify reliable operation with long refuelling interval*
- ✓*Demonstrate SMR competitiveness for different applications*

Project "Common Technologies and Issues for SMRs"

Deliverables

✓**INTERNATIONAL ATOMIC ENERGY AGENCY, Innovative Small and Medium Sized Reactors: Design Features, Safety Approaches, and R&D Trends, IAEA-TECDOC-1451, Vienna (May 2005)**

✓**INTERNATIONAL ATOMIC ENERGY AGENCY, Advanced Nuclear Plant Design Options to Cope with External Events, IAEA-TECDOC-1487, Vienna (February 2006);**

✓**INTERNATIONAL ATOMIC ENERGY AGENCY, Status of Innovative Small and Medium Sized Reactor Designs 2005: Reactors with Conventional Refuelling Schemes, IAEA-TECDOC-1485, Vienna (March 2006)**

✓**INTERNATIONAL ATOMIC ENERGY AGENCY, Status of Small Reactor Designs without On-site Refuelling, IAEA-TECDOC-1536, Vienna (March 2007)**

✓**Appendix 4 of the IAEA Nuclear Technology Review 2007, titled "Progress in Design and Technology Development for Innovative SMRs",**

✓**INTERNATIONAL ATOMIC ENERGY AGENCY, Design Features to Achieve Defence in Depth in Small and Medium Sized Reactors, NUCLEAR ENERGY SERIES REPORT NP-T-2.2 (July 2009)**

✓***INTERNATIONAL ATOMIC ENERGY AGENCY, Approaches to Assess Competitiveness of SMRs, NUCLEAR ENERGY SERIES REPORT (Final Editing, to be Published in 2009)***

✓***INTERNATIONAL ATOMIC ENERGY AGENCY, Final Report of a CRP on Small Reactors Without On-site Refuelling, IAEA-TECDOC (Drafting, to be Published in 2010)***

✓***SMR Inputs for Updateable Electronic Database of Advanced Reactor Designs – In Progress, More Than 30 Designers Preparing Their Inputs***

Economics and Investments

Deployment options for SMRs:

- ***A single SMR goes where there is no option to accommodate a large NPP (and then the competition are non-nuclear options available there)***

- ***A series of SMRs is considered against fewer larger plants of the same total capacity***

IAEA TOOLS – MESSAGE (IAEA-PESS)

INPUT

- Energy system structure (including vintage of plant and equipment)
- Base year energy flows and prices
- Energy demand projections (MAED)
- Technology and resource options & their techno-economic performance profiles
- Technical and policy constraints

OUTPUT

- Primary and final energy mix
- Emissions and waste streams
- Health and environmental impacts (externalities)
- Resource use
- Land use
- Import dependence
- Investment requirements

FIG. 13. A typical MESSAGE application.

IAEA TOOLS - FINPLAN

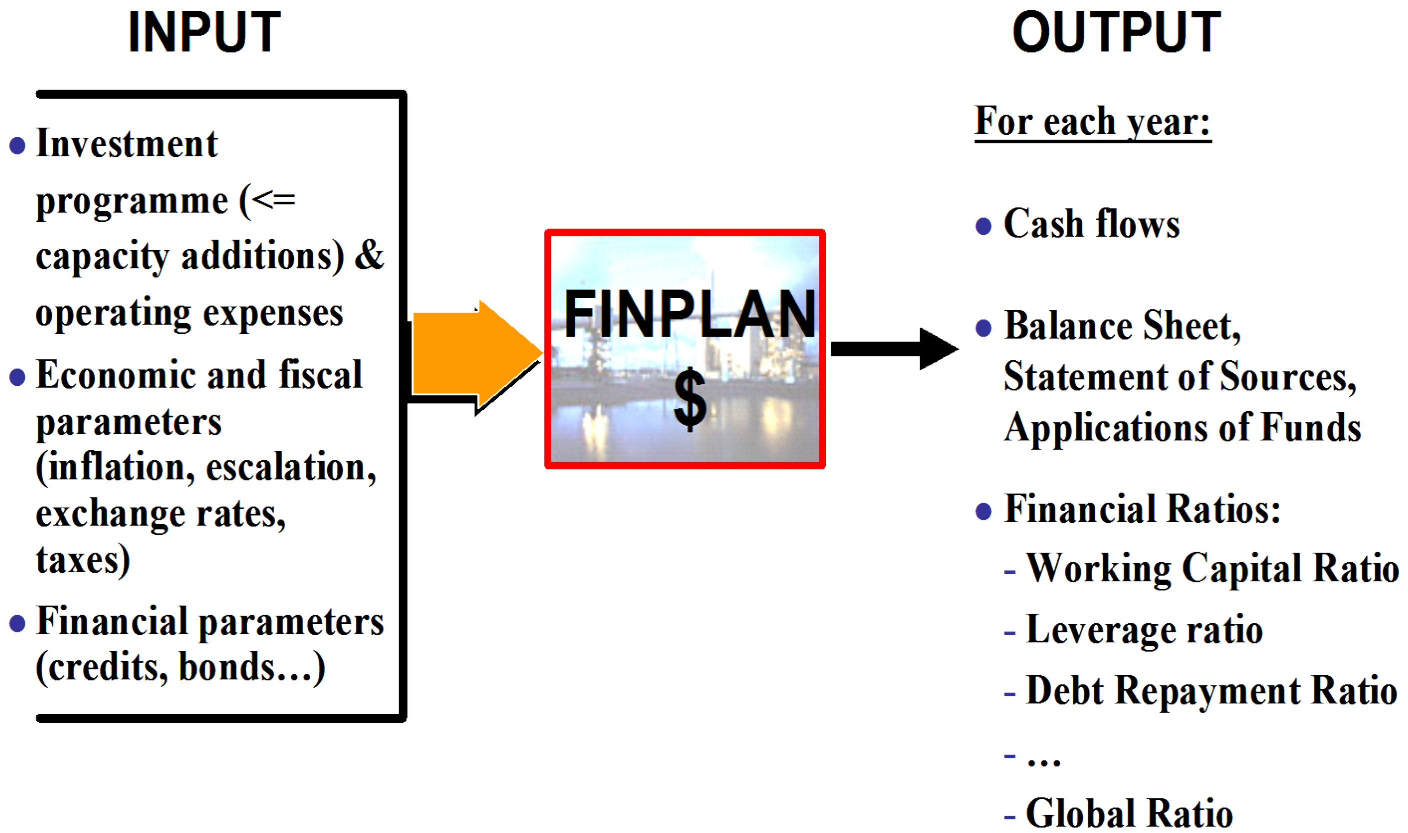


Figure 7. Main inputs and outputs of FINPLAN [10].

Economics – Basic Approach

***G4-ECONS Model:* angelique.servin@oecd.org**

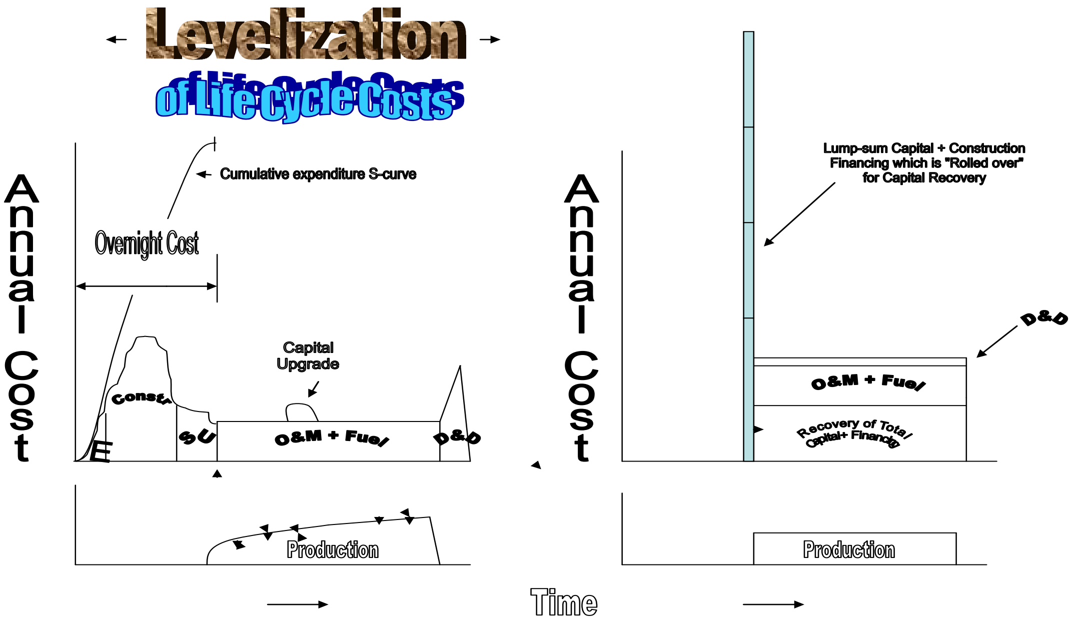
LUEC = LCC +[(FUEL+O&M+D&D)/E]

LUEC – Levelized Unit Electricity Cost

LCC – Levelized Cost of Capital

E – Average annual electricity production MW-hour

Assumption: Constant annual expenditures and production



Small or Medium Sized Reactor Does not Mean a Low Capacity Nuclear Power Station

- Several SMRs can be built at a single site; twin units are possible
- Many of innovative SMRs provide for power station configurations with 2, 4, or more NPPs or reactor modules .

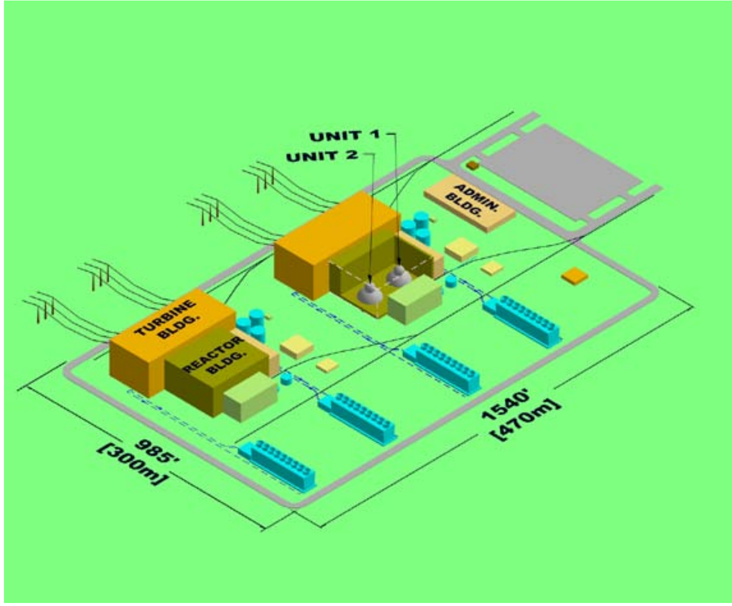


FIG. II-10. Perspective view of IRIS multiple twin-unit site layout.

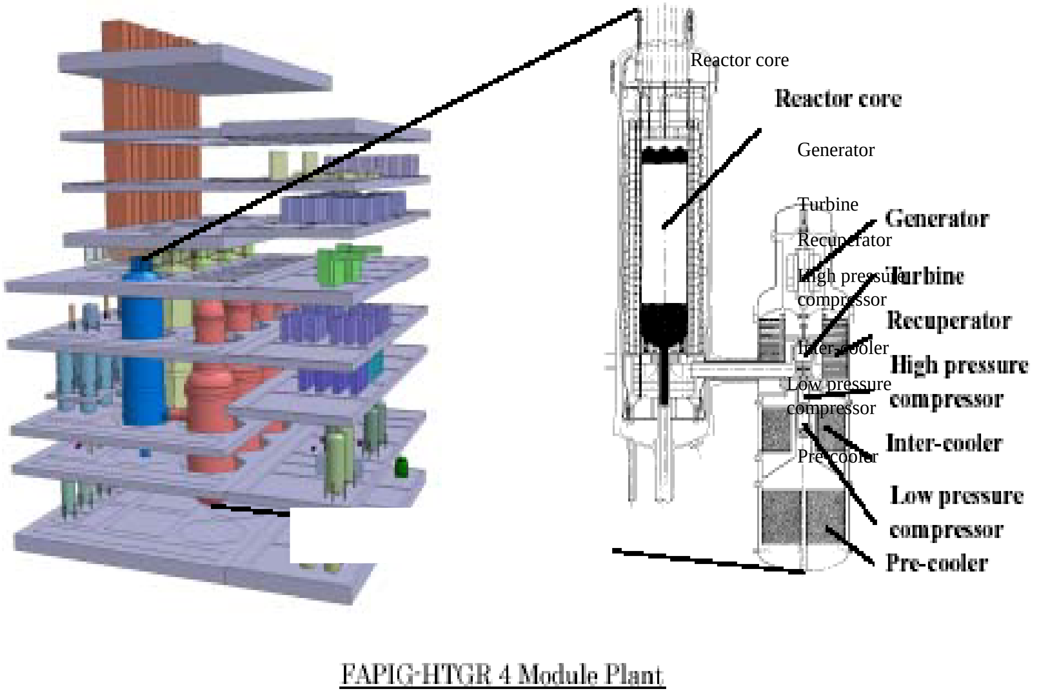
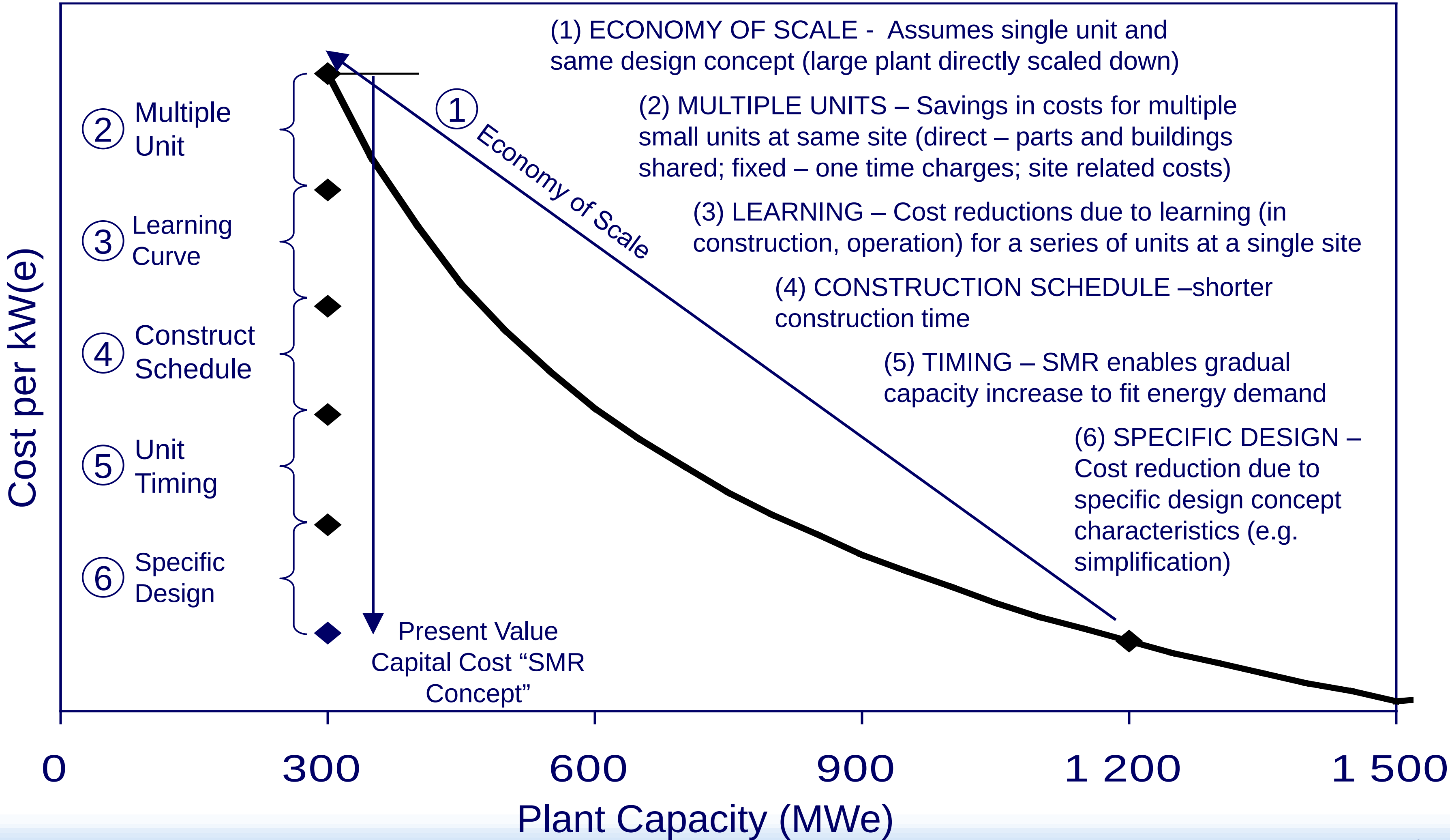
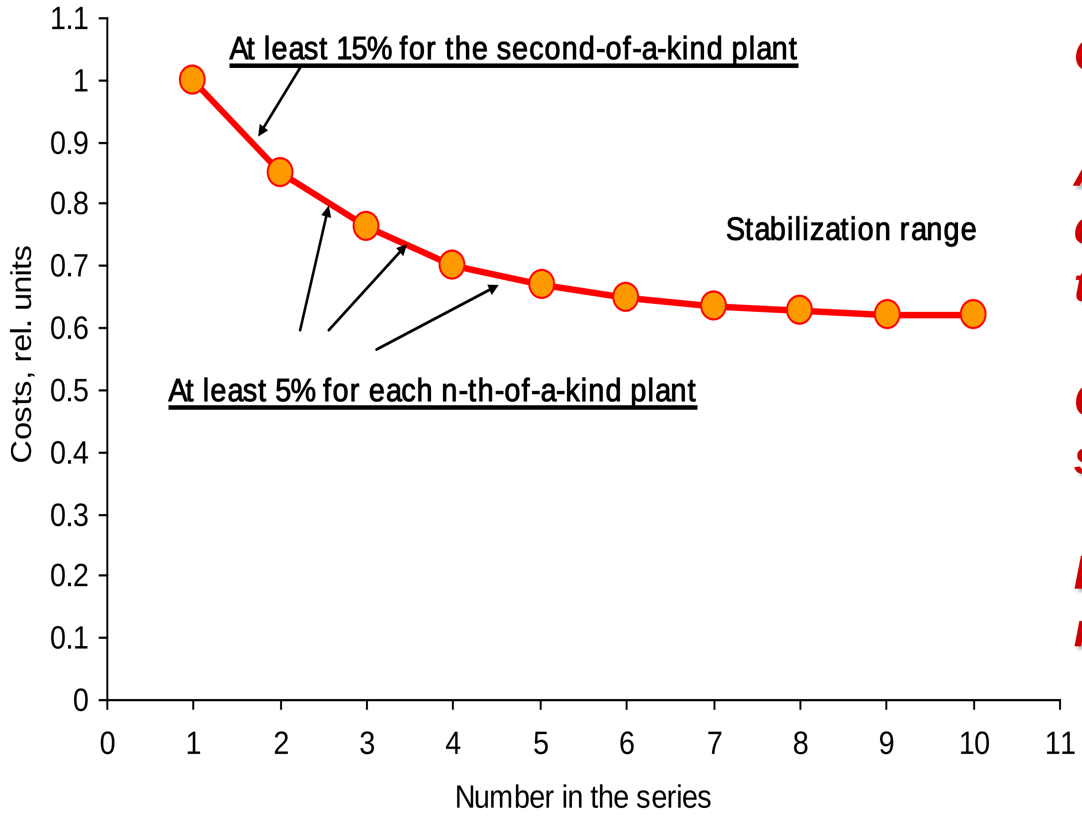


Fig. XVIII-1. Schematic view of the FAPIG-HTGR 4-module plant.

Present Value Capital Cost (PVCC) Model – Westinghouse, USA



Learning Curve – Capital Cost Reduction; Example (OKBM, Russia)



- ***Learning Curve Applicability:***

Only valid within a country

Assumes no substantial changes to regulations over time

Cannot be extrapolated to new sites with new reactors

Depends on continuity in reactor build-up

Economics Taking Into Account PVCC – A Simple Case Study
Present Value Capital Cost (PVCC) Model – Westinghouse, USA

Table 1. Assumptions for the test case.

SMR to large reactor capacity ratio	1:4
Scaled large reactor cost	Based entirely on large reactor design scaled to 1:4 ratio
SMR unit timing	Every 9 months
Discount rate	5% per year

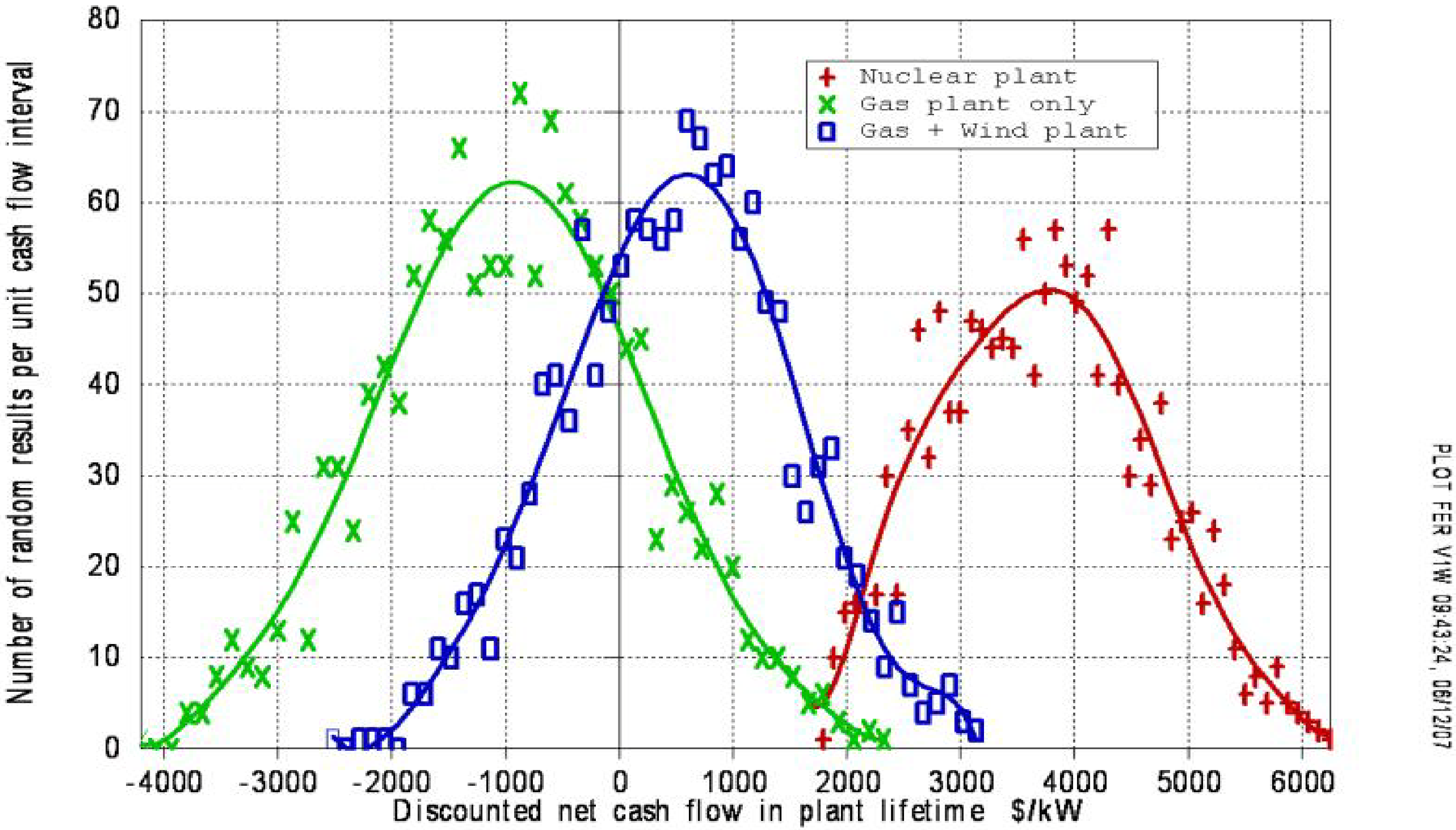
Table 2. Results of SMR capital cost factor model.

Capital cost factor	*Capital cost factor ratio (Four SMRs versus single large reactor, see Table 1)*		
	Overnight capital cost	*Total capital investment cost*	*Present value capital cost*
(1) Economy of scale	1.74	1.74	1.74
(2) + (3) Multiple units plus Learning	0.78	0.78	0.78
(4) Construction schedule	N/A	0.95	0.95
(5) Unit timing	N/A	N/A	0.94
(6) Design specific factor	0.85	0.85	0.85
Cumulative Total	*1.16*	*1.09*	*1.04*

The initial 74% economy of scale penalty is largely offset by capital cost improvement factors!

TAKING INTO ACCOUNT UNCERTAINTIES – Case Study by FER (University of Zagreb, Croatia)

Discounted net cash flow in plant lifetime (40 years)



Source: Ref. (1)

Economics and Investments

Economics

G4-ECONS Model: ***angelique.servin@oecd.org***

$$LUEC = LCC + [(FUEL + O\&M + D\&D)/E]$$

LUEC – Levelized Unit Electricity Cost

LCC – Levelized Cost of Capital

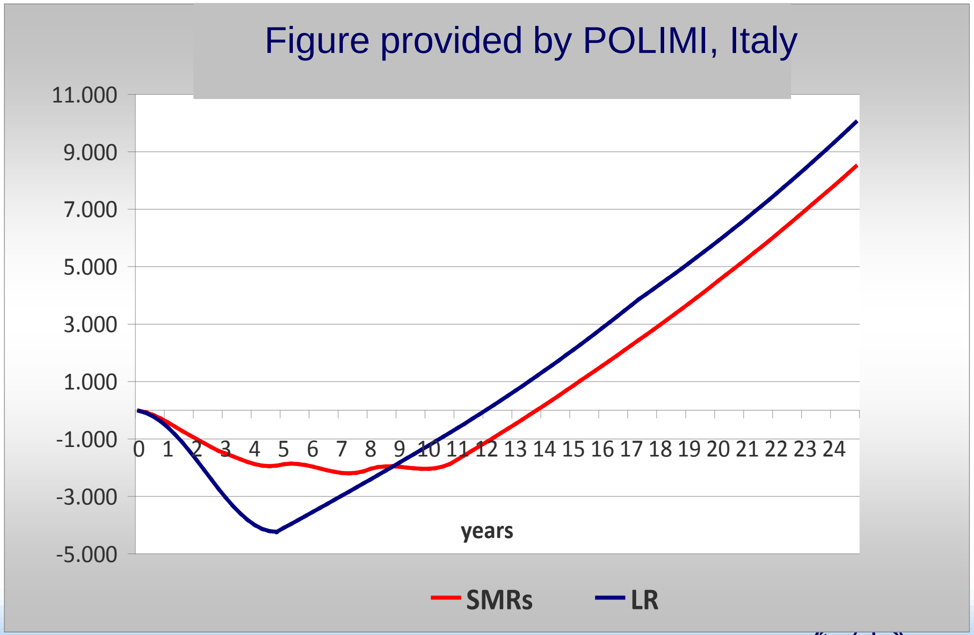
E – Average annual electricity production MWh

Assumption: Constant annual expenditures and production

Investments and Revenues

Important Factors:

✓ ***Time-Dependent Expenditures and Production, Interest Rates -> Uncertainties and Sensitivities***



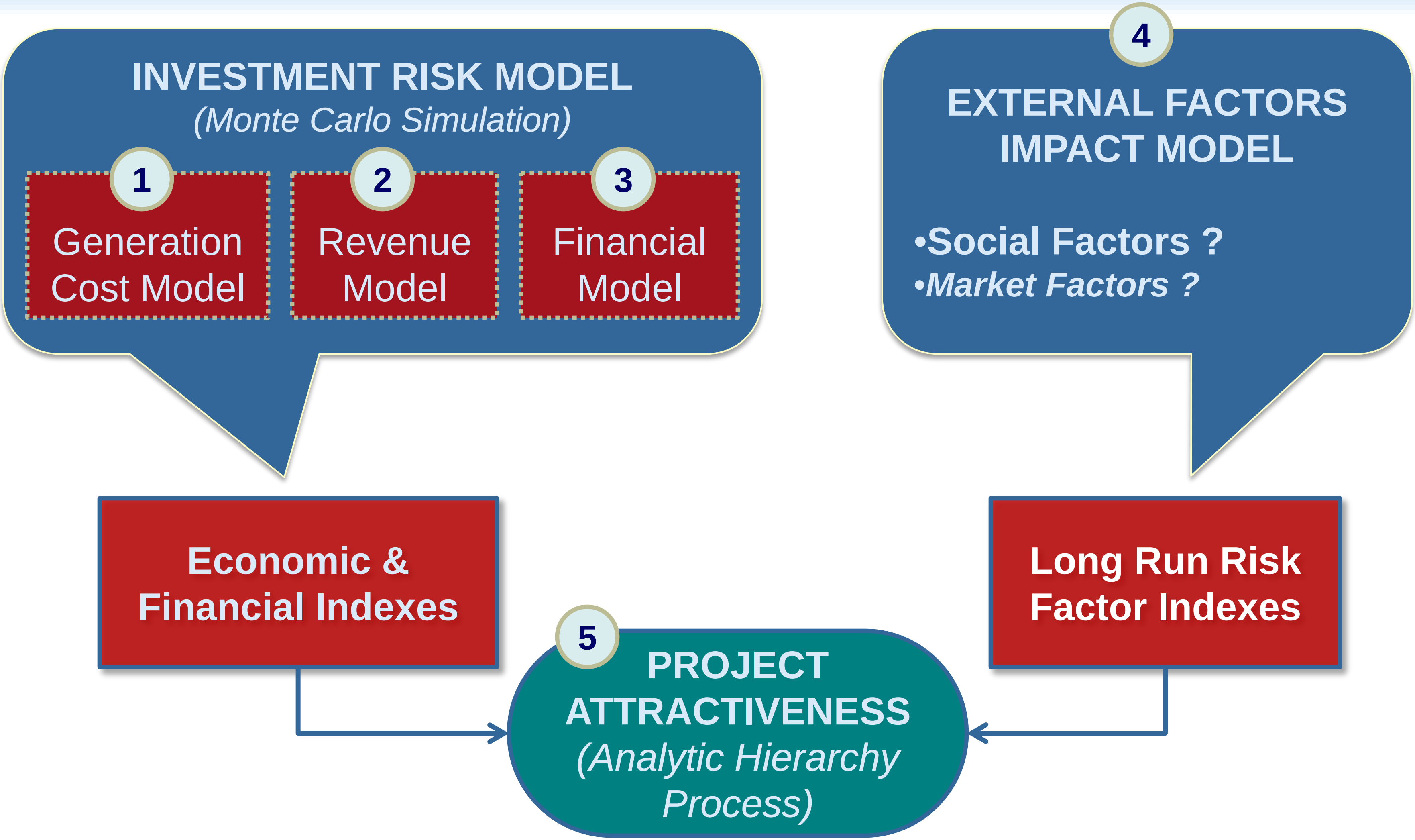
- **A variety of models and tools addressing different aspects of a comparative economic assessments of SMRs versus larger reactors exist in member states or are available from international organizations**

- ***Consolidated approach to the application of all these models is not established yet***

- ***Many SMRs are at early design stages and full data needed for economic analysis is not yet available***

- ***Advanced SMR designers need simple but comprehensive economic assessment tools capable of guiding the design development from early stages***

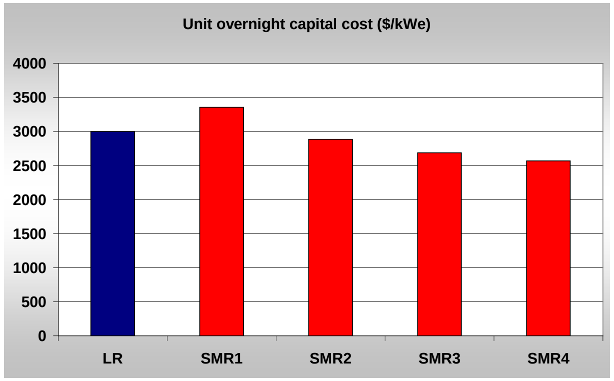
NEW MODELS AND SOFTWARE (EXAMPLES)

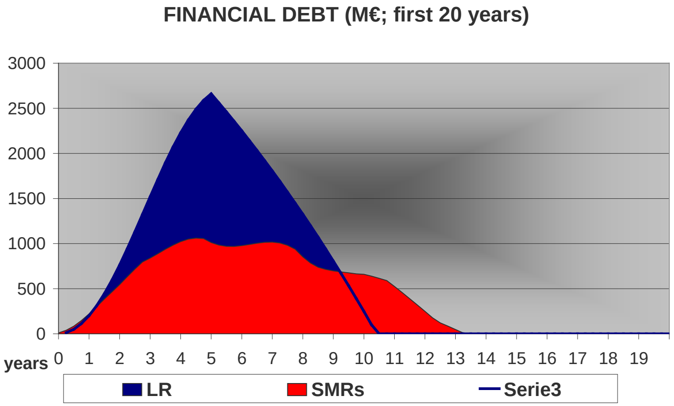


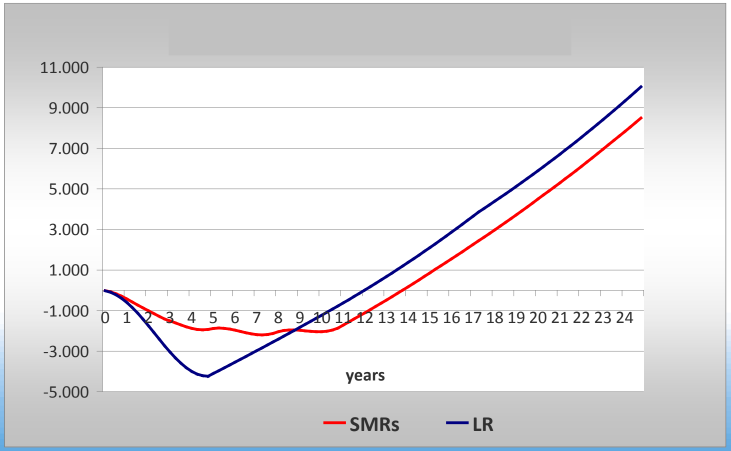
Integrated model for Competitiveness Assessment of SMRs – INCAS (POLIMI, Italy)

The benefits of Investment Scalability - Case Study By Politecnico Di Milano (Italy)

- **Incremental capacity reduces the required front end investment and the Capital-at-Risk**
- **Lower Interest During Construction compensates higher overnight costs:**
  - ***Lower Total Capital Investment cost of SMRs vs. Large Reactors***
- **Capital structure is more balanced and risk of default is lower**
- **SMRs may bear a higher financial leverage during construction.**
- **SMRs are able to absorb construction delay without heavy financial shock**
- **Profitability is comparable between LR and SMRs in terms of NPV and IRR**
- **Trade-off: excessively staggered construction delays full site power availability to the grid and lowers NPV of the project (by shifting cash inflows onwards).**





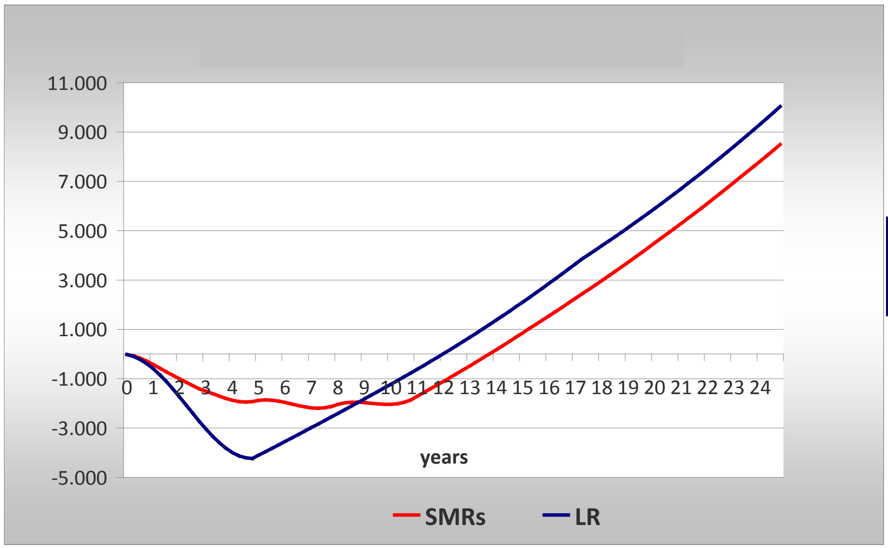


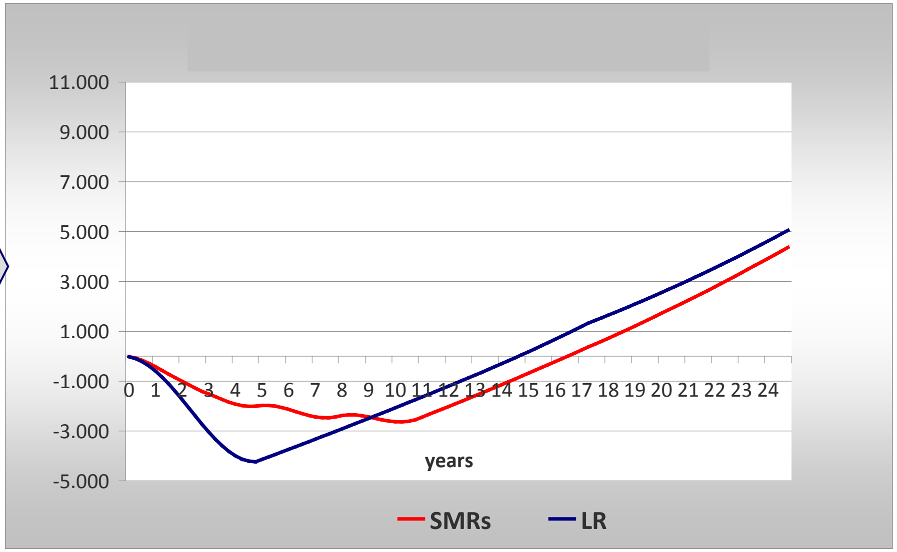
Paper 1S01, WR09 Intl. Conf., IAEA, 27-30 October 2009

IAEA ACTIVITIES

✓**INTERNATIONAL ATOMIC ENERGY AGENCY, Approaches to Assess Competitiveness of SMRs, NUCLEAR ENERGY SERIES REPORT (Final Editing, to be submitted for publication in September 2009)**

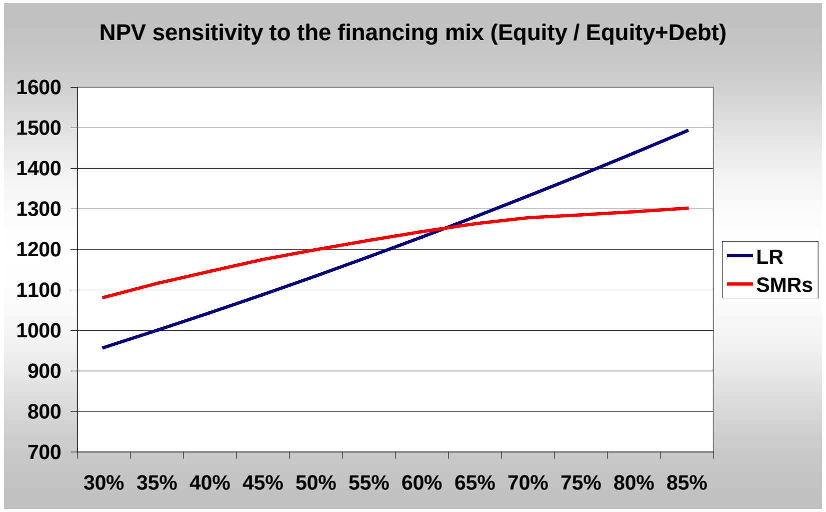
✓**Ongoing IAEA Activity – CASE STUDIES ON COMPETITIVENESS OF SMRs IN DIFFERENT APPLICATIONS**

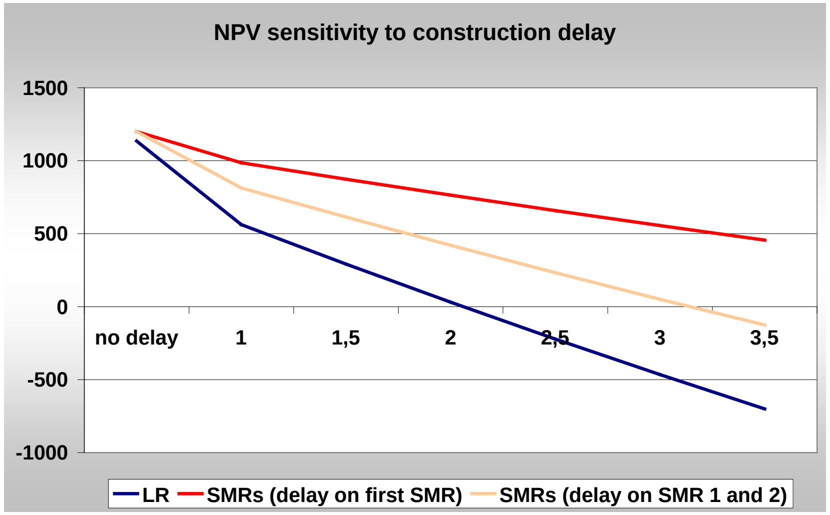


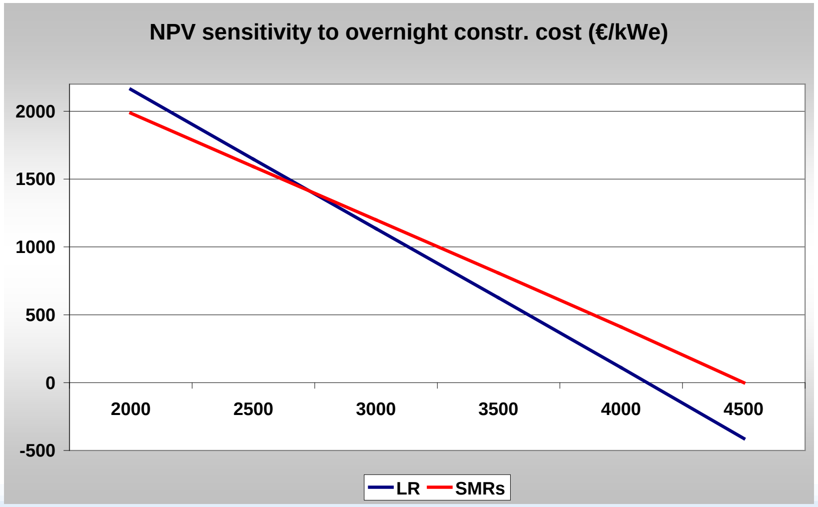


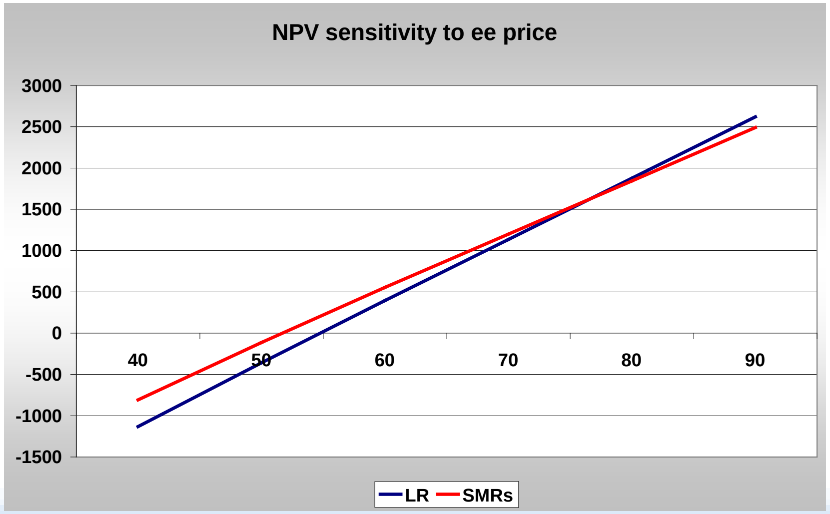
POLIMI (Italy) Case Study: Electricity price decrease from 70 cents/kWh to 60 cents/kWh

POLIMI (Italy) Case Study – INCAS Investment Model: Example of Results









SMRs Could Be Cheap If Indigenously Produced in Countries with High Purchasing Power of Hard Currency

Options for Immediate Deployment:

- ***CANDU6/ EC6 AECL (Canada)***
- ***PHWR-220 – being built in India; PHWR-540 (NPCIL, India), 1800 US$/kW(e)***

- ***Chinese PWRs of 325 MW(e) (China) – being built in Pakistan; and 610 MW(e) – being built in China***

Conclusions (1)

- **When investing in reactor technology, the typical choice is not between a single SMR and a single large reactor but rather between a nuclear power option in general (large reactor or SMR, whichever fits within a certain niche) and the competing non-nuclear energy technologies, such as gas, coal, hydro, renewables, etc.**

- **Or, alternatively, between a single large reactor and a group of sequentially built SMRs, intended to yield the same aggregate power**

- **When assessing sequential deployment of several reactors, factors related to multiple units, learning, construction schedule, unit timing, and plant design should be taken into account, in addition to the economy of scale**

Conclusions (2)

- Uncertainty analysis needs to be incorporated to consider risks and add a degree of fidelity to the overall assessment
- A variety of models and tools to address different aspects of a comparative economic assessments of SMRs versus larger reactors exist in member states or are available from international organizations
- *Consolidated approach to the application of all these models is not established yet*
- Advanced SMR designers need simple but comprehensive economic assessment tools capable of guiding the design development from early stages

Conclusions (3)

- **Consolidated approaches are being developed in some member states, and the IAEA keeps a track of these developments and conducts a series of national Case Studies on assessment of SMR competitiveness in different applications**

The results of the completed case studies indicate that some SMRs could compete with large reactors in some applications.

THANK YOU!

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BACK-UP VIEWGRAPHS

Attractive Common Features of SMRs

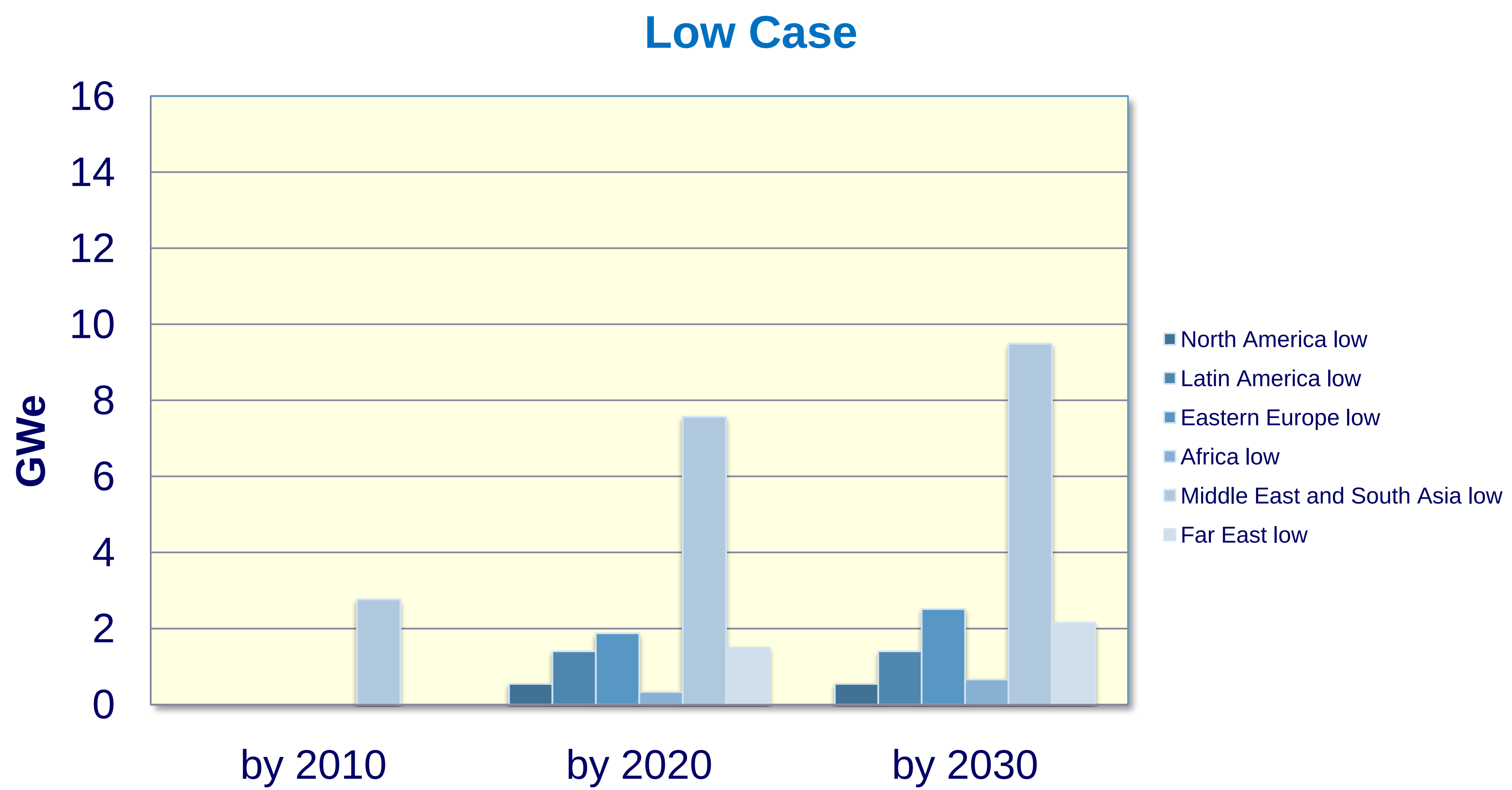
- ***Option of incremental capacity increase, flexible and just-in-time capacity addition***

- ***Potentially, smaller emergency planning zone and proximity to the users***

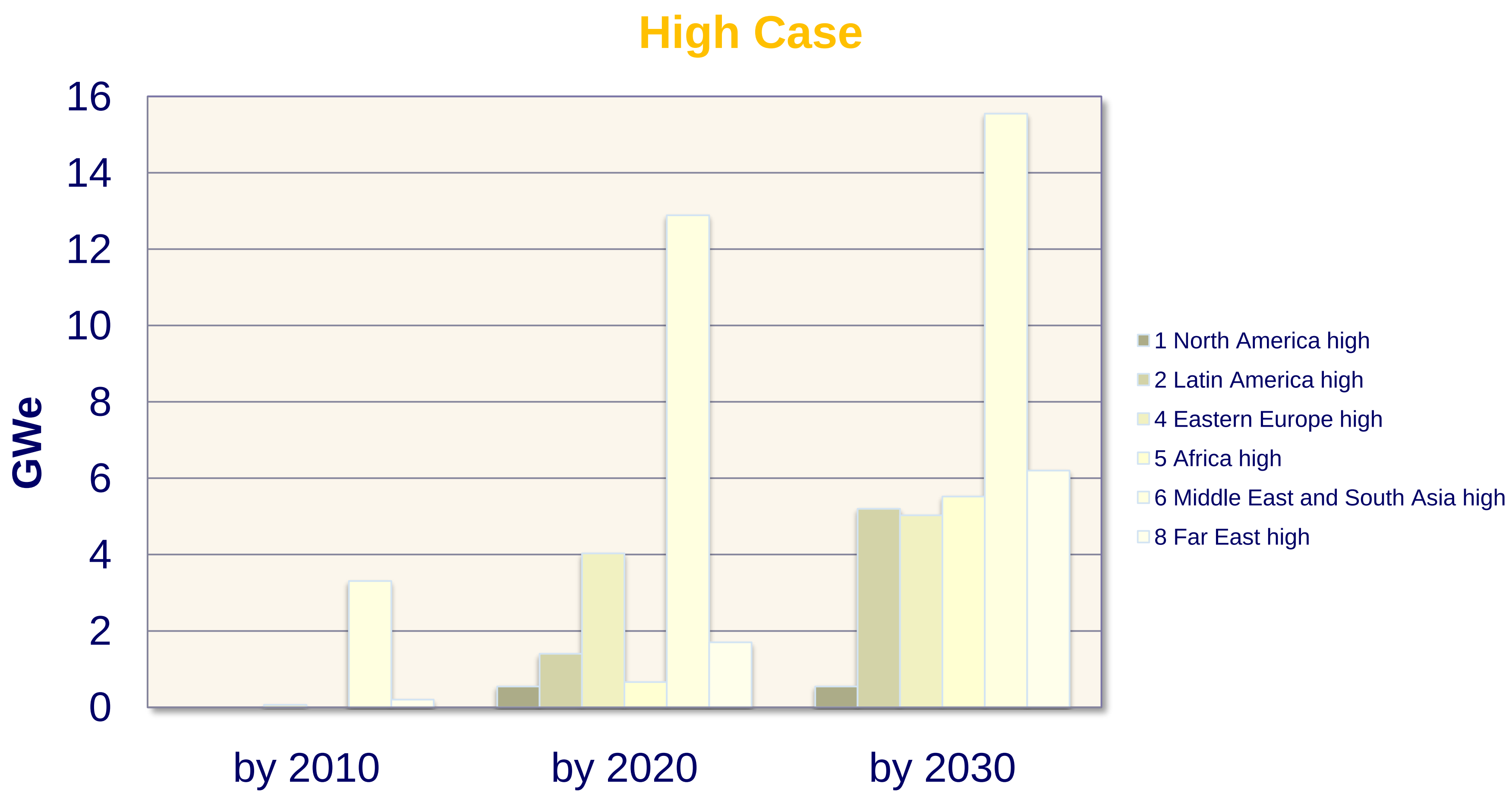
- ***A variety of flexible and effective non-electrical application options (i.e., co-generation)***

- ***For small reactors without on-site refuelling: long refuelling interval and reduced obligations of the user for spent fuel and waste management***

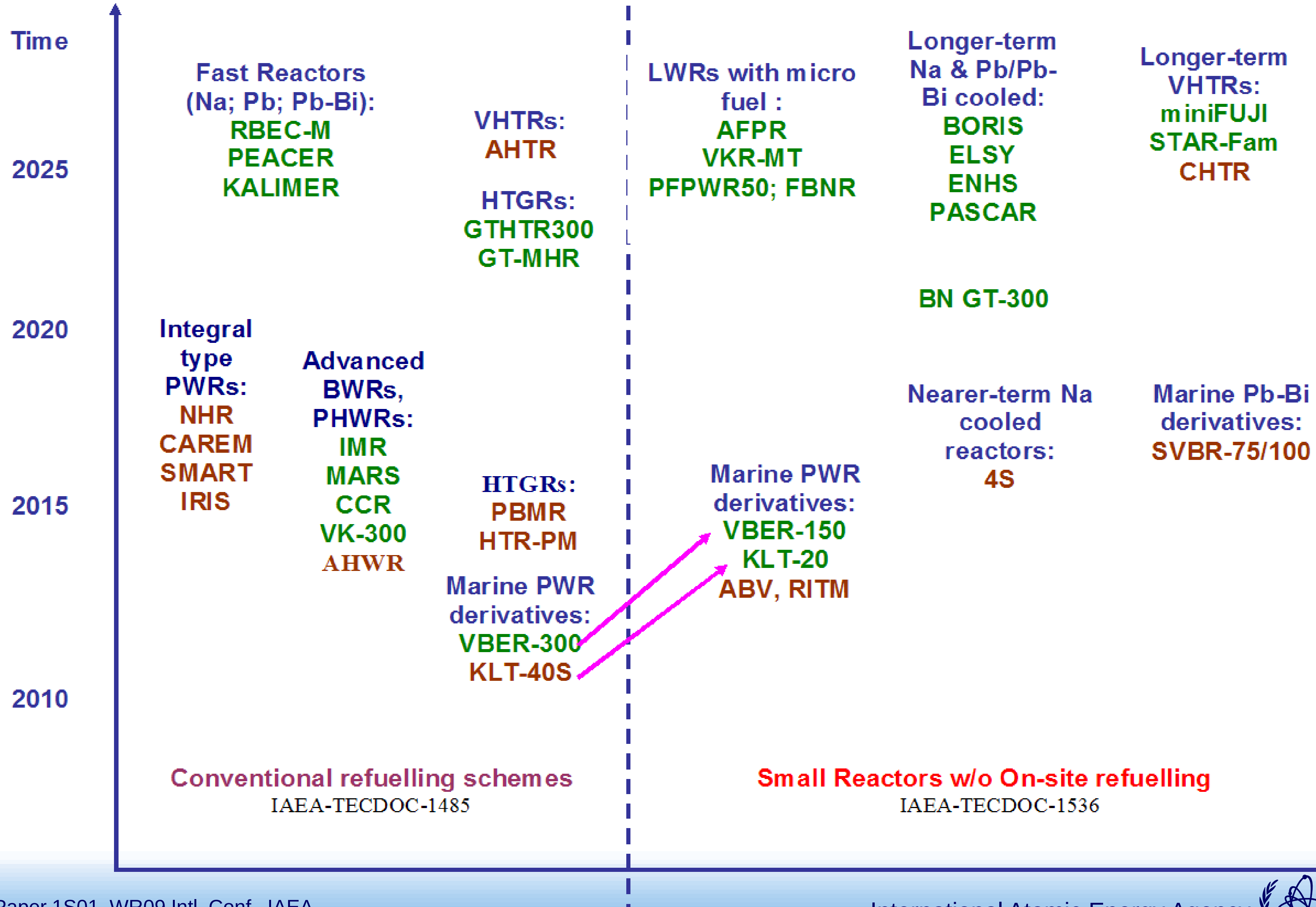
SMR estimates extracted from RDS-1 2008



SMR estimates extracted from RDS-1 2008



Deployment potential of innovative SMRs



What would happen if this is not done?

- *All innovative SMRs are licensable against current safety requirements and regulations*

- *There are established methods for validation of passive safety systems*

- *Reduced EPZ can be partly justified using current regulations in some countries*

- *Long refuelling interval has experience with submarines*

✓ *Competitiveness of SMRs needs to be demonstrated*

IAEA TOOLS – MESSAGE (IAEA-PESS)

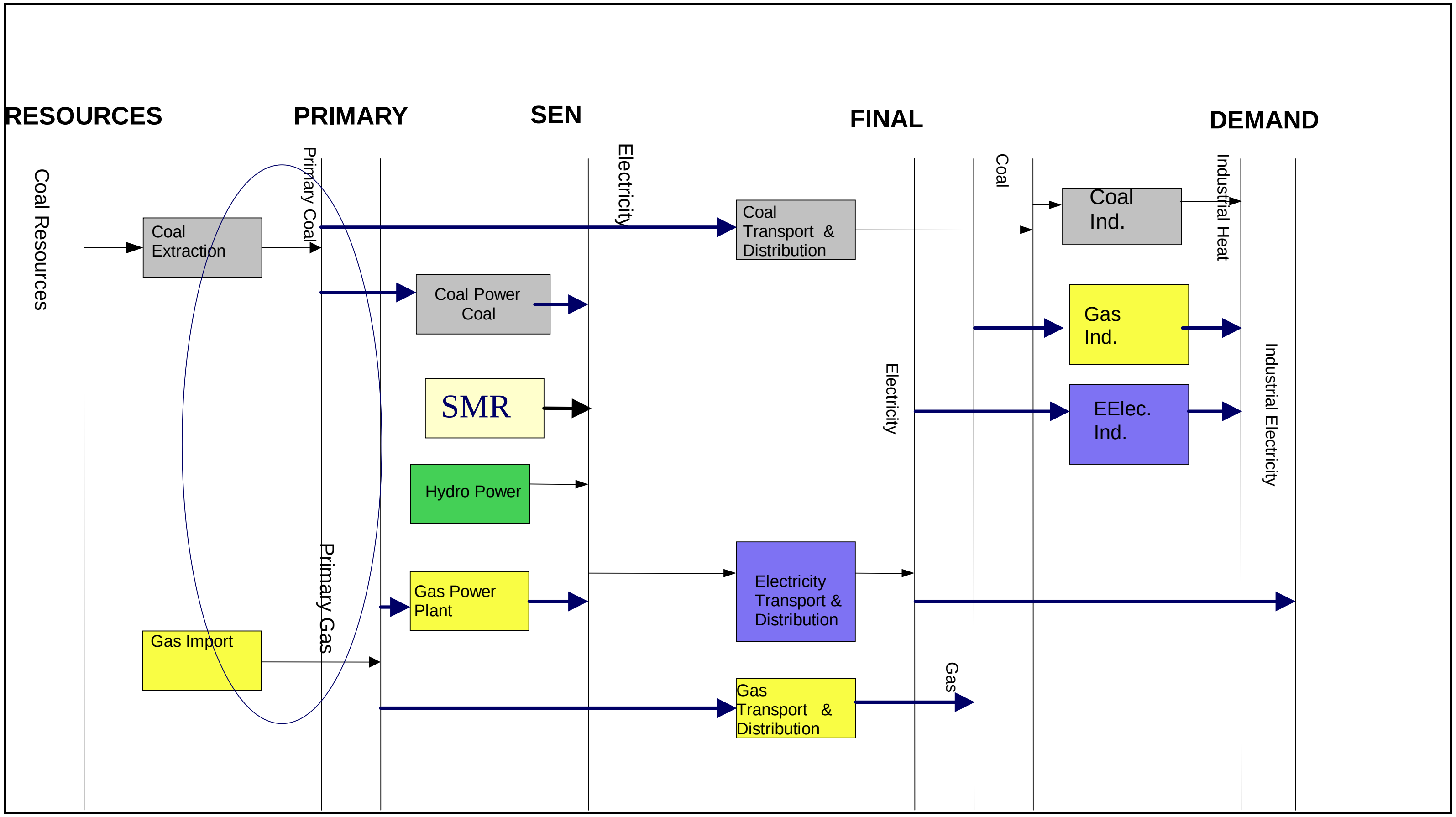


Figure. 6. A simple energy supply model in MESSAGE – physical flow [4].