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Multi-regional Transitional Strategies Towards Fast Reactor Based Nuclear Energy Systems

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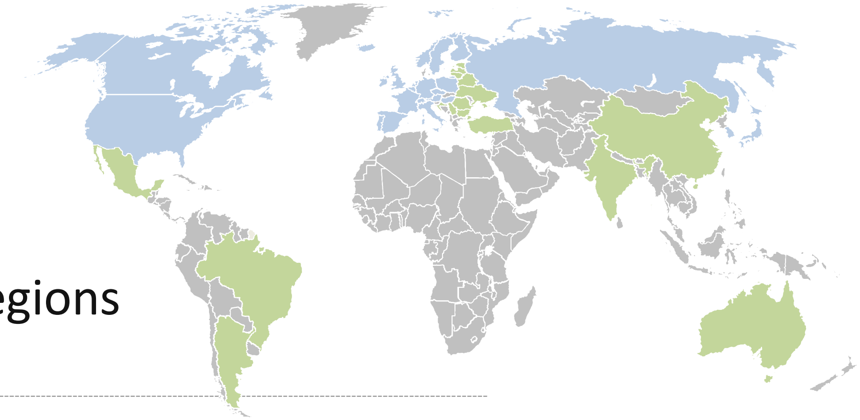
OUTLINE

- World Nuclear Energy Demand Forecast
- Multi-regional Deployment Strategies
- Multi-regional Transitions Scenarios
- Summary

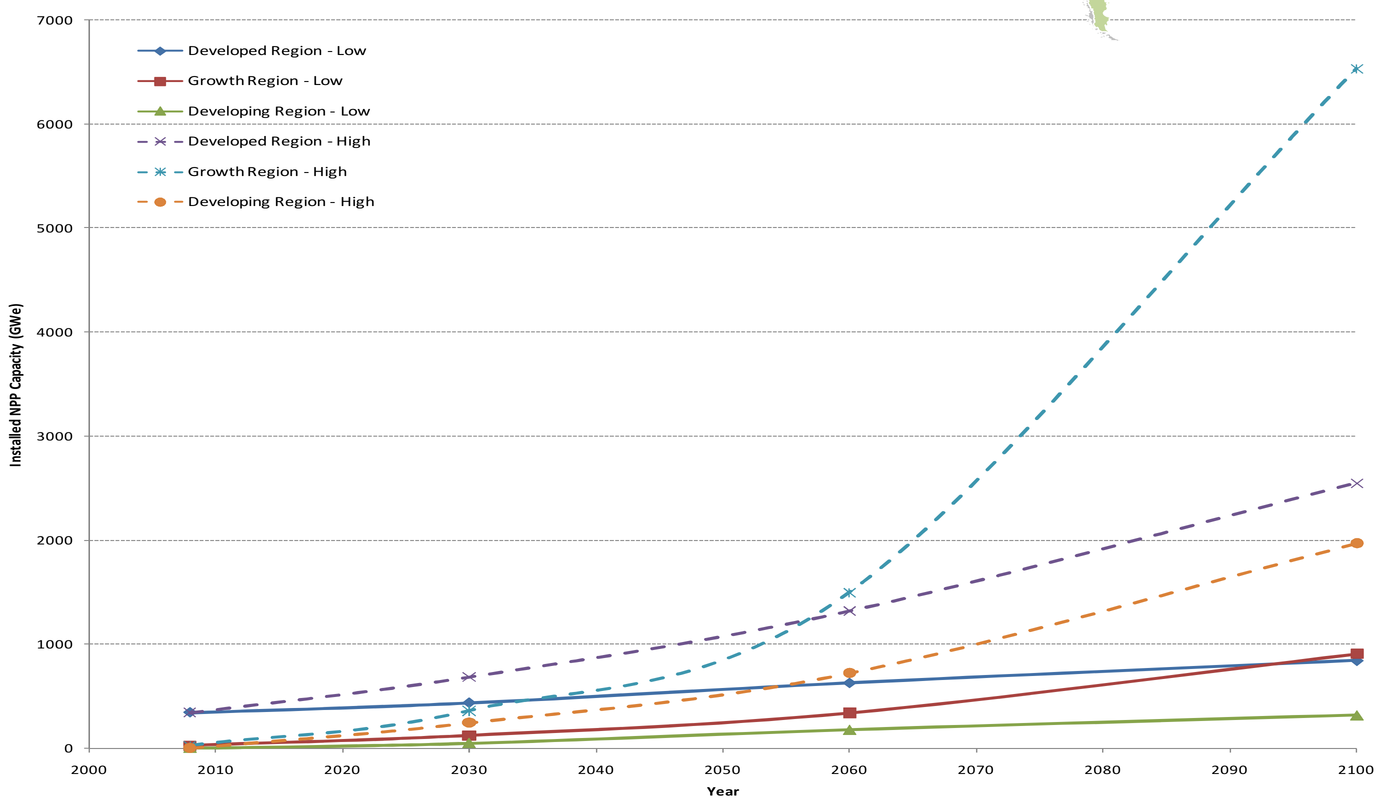
World Nuclear Energy Demand Forecast

- Different forecast studies with wide range of prediction of possible nuclear energy growth
  - Forecast range up to 10,000 GWe or more by 2100
  - IAEA, BP, NEA, IIASA, IPCC, WNA, ..
  - Some studies go to 2030 up to 2050 and only a few go to 2100 such as the IIASA, IPCC, WNA
  - Usually high, moderate, and low growth predictions
- WNA 2008 forecast is used here
  - Not to be considered as projections, but more as illustrative scenarios showing what nuclear energy might provide to the world's energy needs.

World Nuclear Energy Demand Forecast



- WNA Predictions
  - 3-regions, low and high scenario
  - Developed, growth, and developing regions



World Nuclear Energy Demand Forecast

- Advanced nuclear energy systems will be part of this growing nuclear energy future gradually replacing existing Generation – II and – III N ultimately transitioning towards Generation – V type NPP.
- Fast reactors are expected to be a major component of such advanced nuclear energy systems (OECD/NEA report on issues raised by transition to FR)
  - Transition scenarios to fast reactors offer efficiency of natural resource utilization, security of supply, and radioactive waste management options.

Motivation for Regional View on Nuclear Energy Deployment

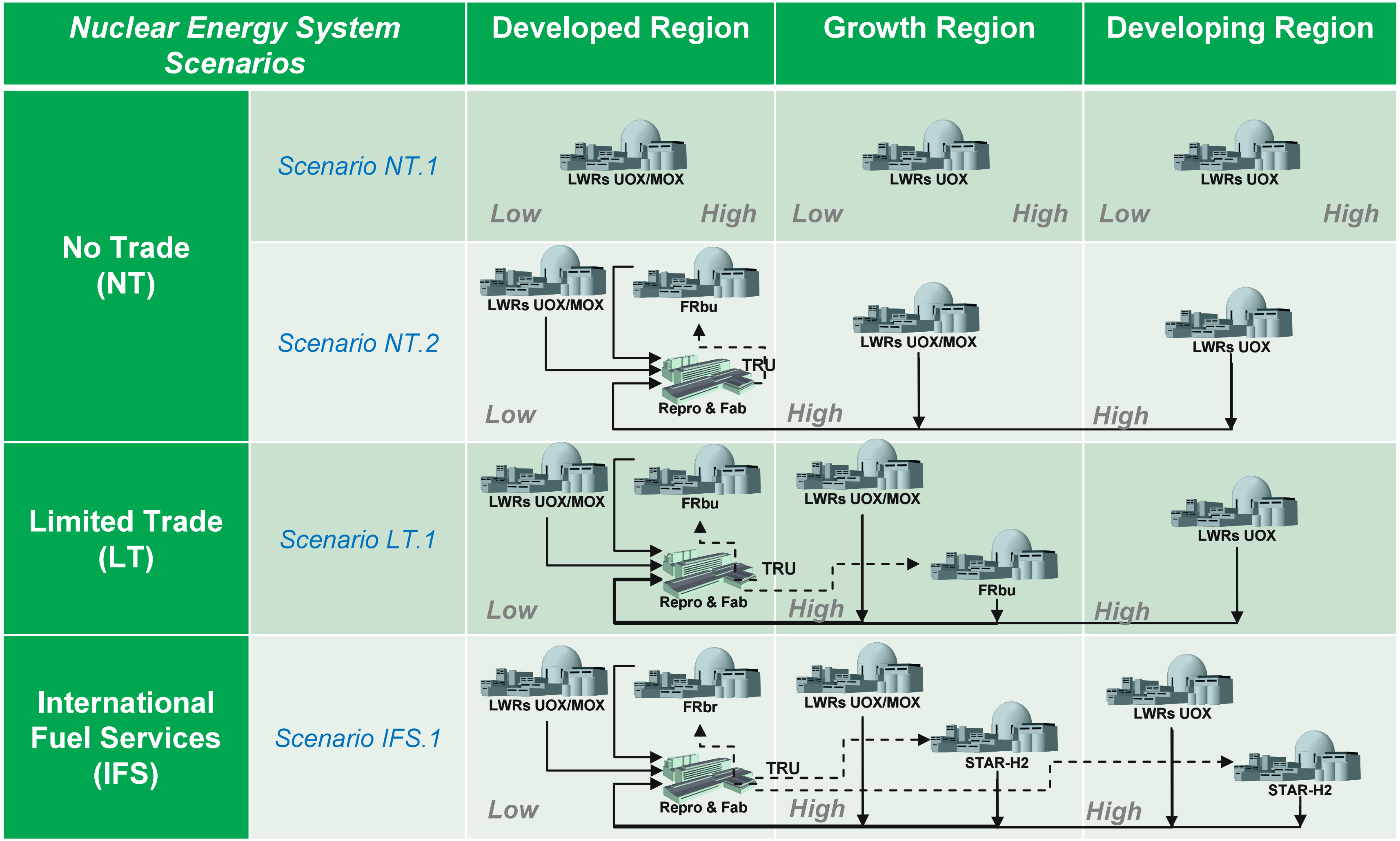
- Differences in (energy) market and nuclear technology base

	Developed Regions	*Growth Regions*	*Developing Regions*
Current Nuclear Industrial Capability			
Industrial Infrastructure	Robust	Significant	Lacking
Labor Market	Skilled, Expensive	Skilled, Less expensive	Less skilled, inexpensive
Access to Capital	Robust	Robust	Constrained
Energy Market organization			
Liberalized/deregulated	Yes	No	No
Investors energy market	Private	Private/Government	Government/Private
Investment criterion	Shareholders value creation	Shareholders value creation	Capital requirements
Nuclear Power Plants			
Nuclear deployment	Initially high, replacement market, later-on small	Initially small, but steadily and possibly high growth	Small with potential for steady growth
Nuclear technology generation	Gen-II and III, gradual introduction of Gen-IV in a replacement market	Gen-II and III, Some Gen-IV introduction as part of regional fuel cycle service centre	Gen-III and Gen-IV
Emplaced grid and favored plant size	Large	Small to Large	Small
Energy services	Electricity Hydrogen	Electricity Process Heat Water Desalination Hydrogen	Electricity Process Heat Water Desalination Hydrogen

Motivation for Regional View on Nuclear Energy Deployment

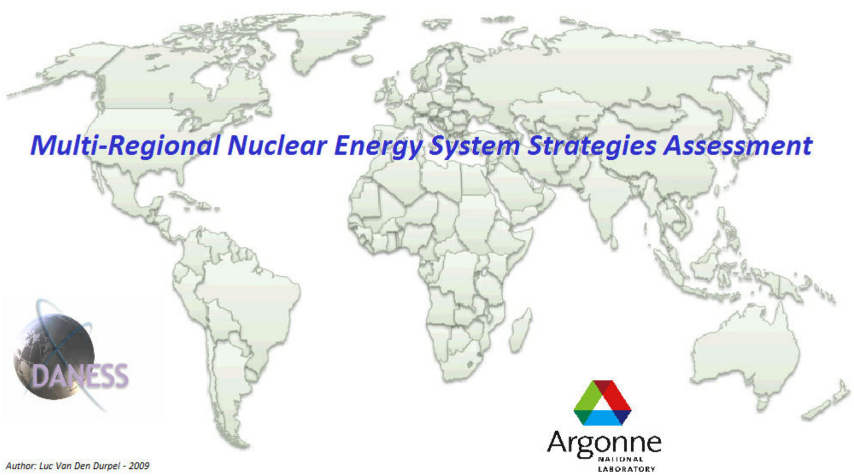
Nuclear Fuel Cycle Infrastructure			
SNF-inventory already existing and in the pipeline, i.e. current fissile material working inventory	Large	Small	Very small
Current access to indigenous enrichment and fuel fabrication facilities	Yes	Yes	No
Current access to indigenous reprocessing and “hot” fuel fabrication facilities	Yes – for MOX as waste management time delay	Some	No

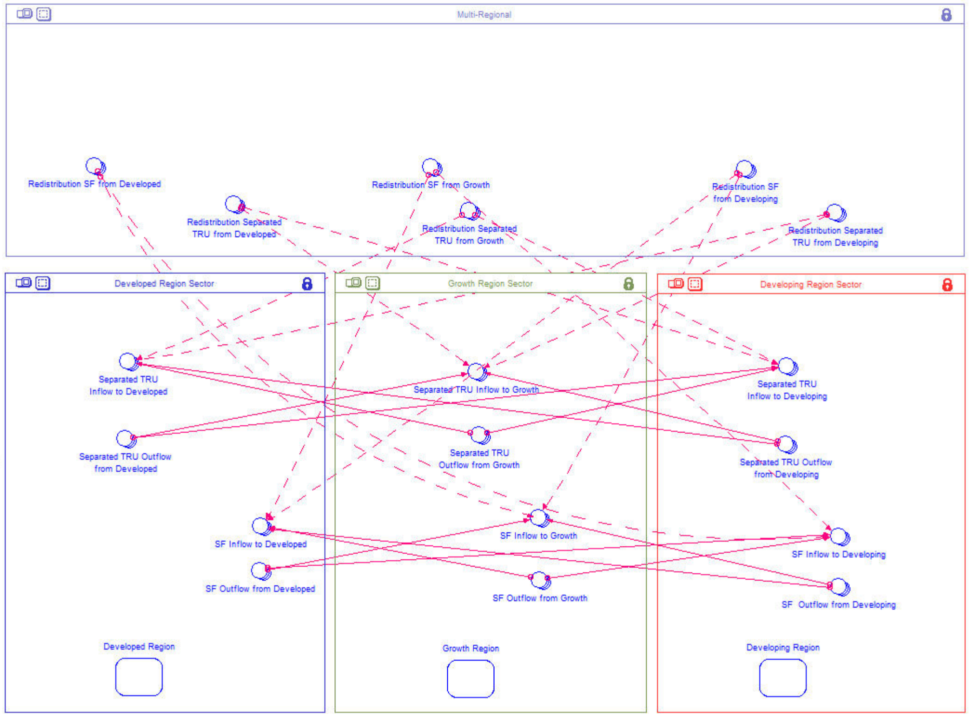
Multi-regional Scenarios Considered in Study



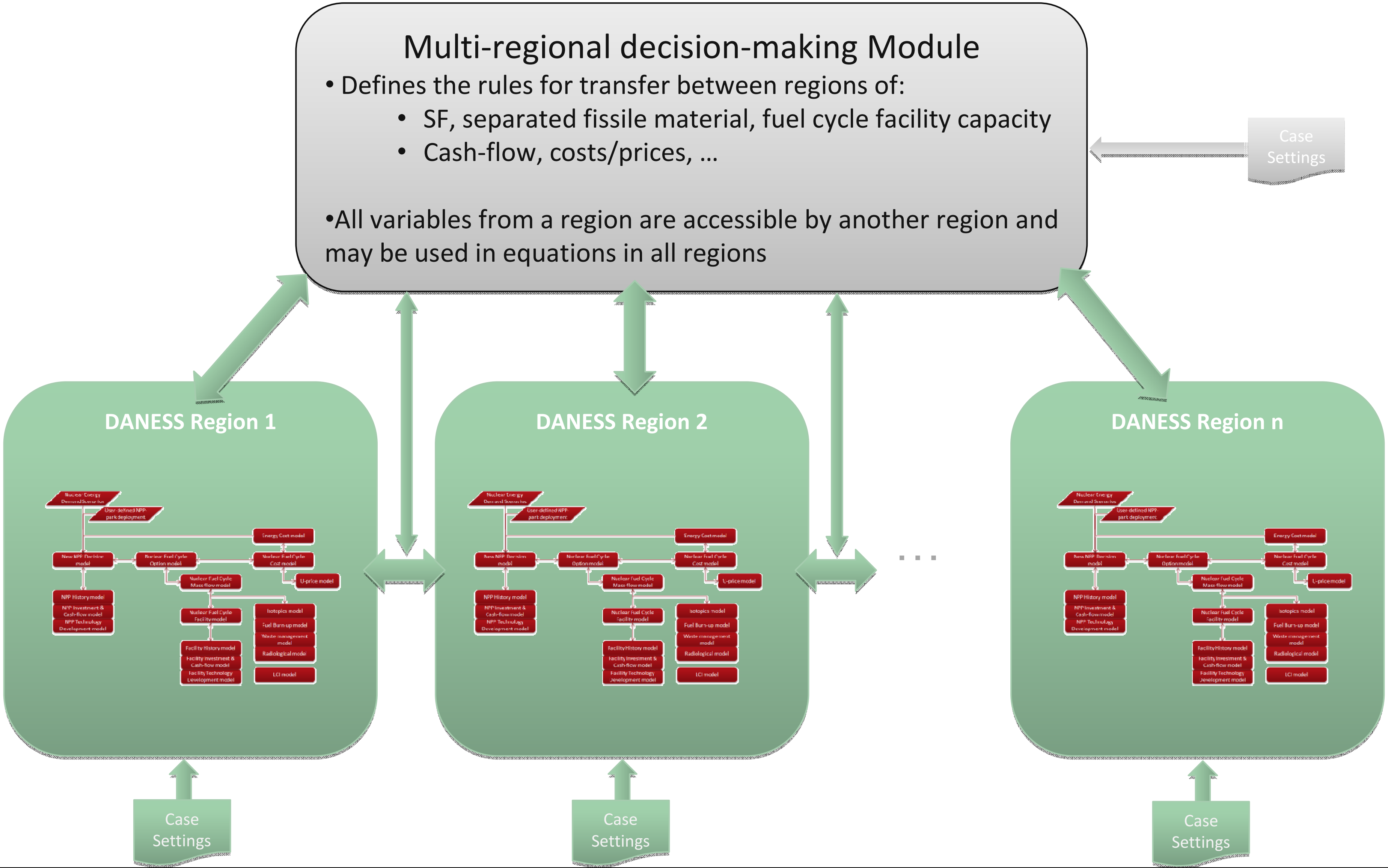
Simulation Capabilities

- DANESS (Dynamic Analysis of Nuclear Energy System Strategies)
  - System dynamics simulation of integrated nuclear fuel cycle systems
  - Current version to be released v.5.0
  - Multi-regional version



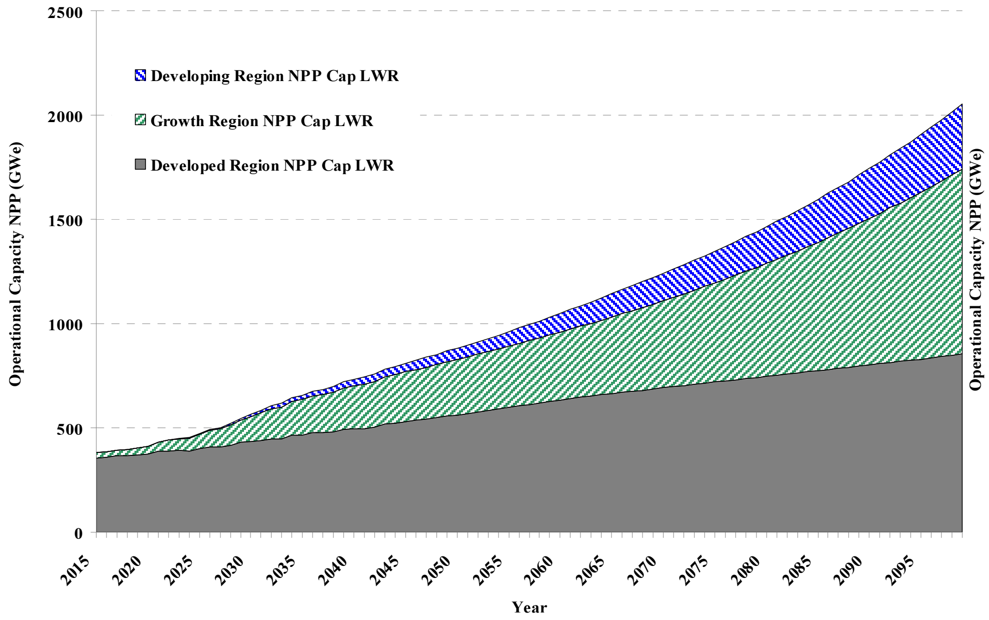


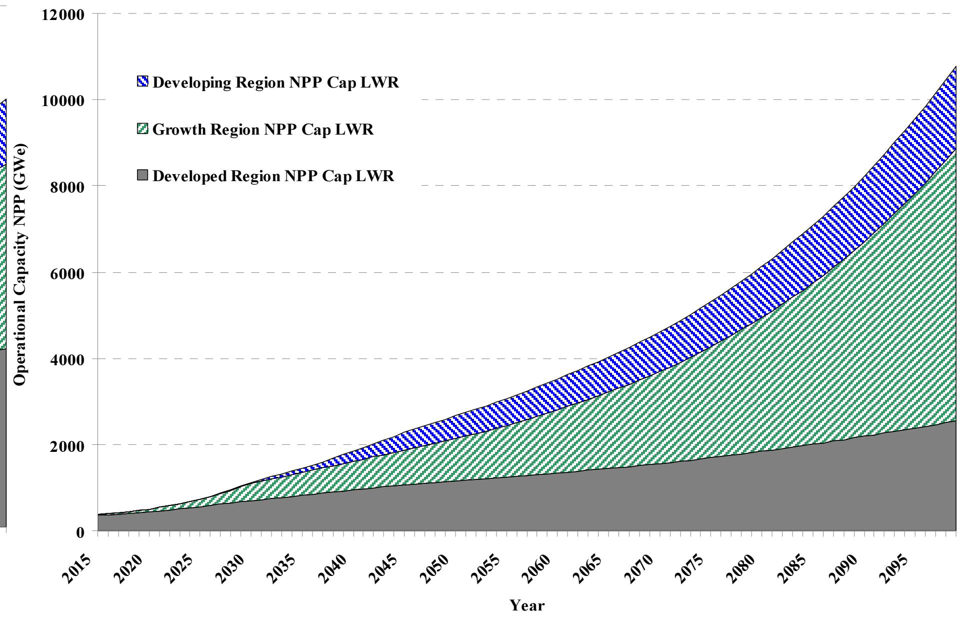
Multi-regional DANESS Modeling



Multi-regional Transitions Scenarios

NT.1 No Trade LWR UOX/MOX Deployment Nuclear Power Park





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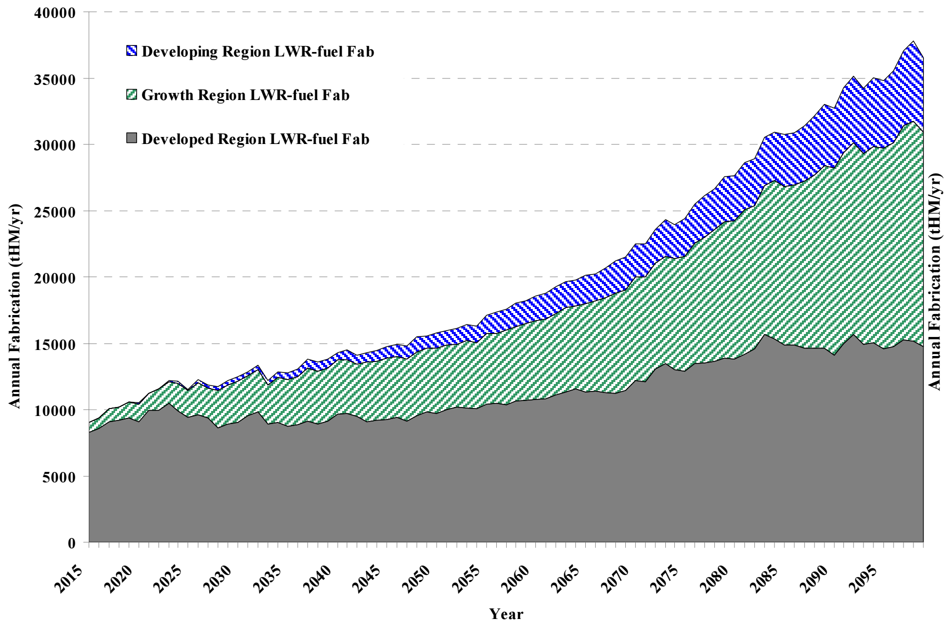
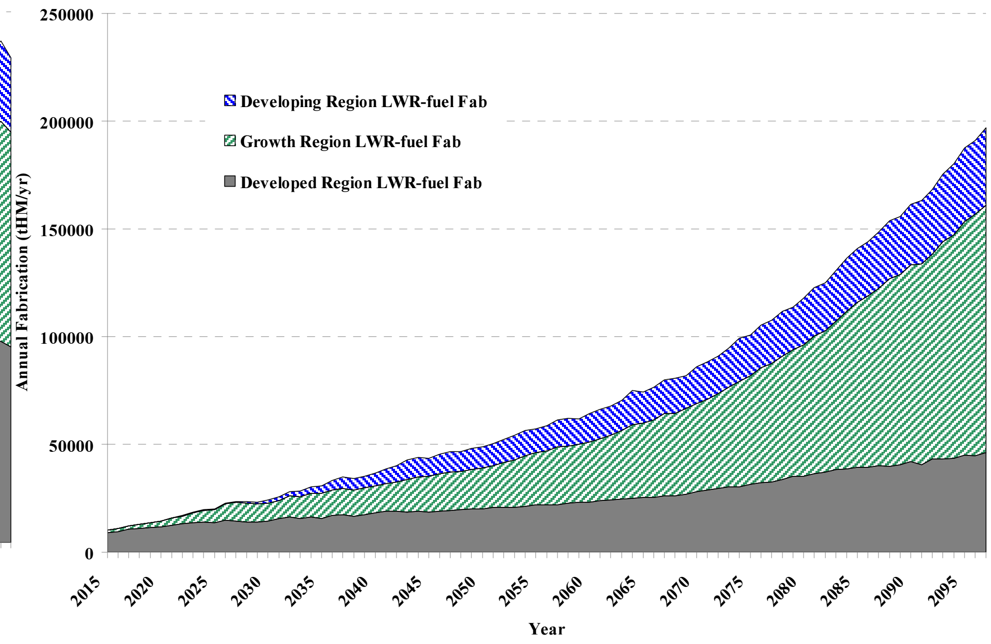
NT.1 No Trade LWR UOX/MOX Deployment
Fuel Fabrication Demand





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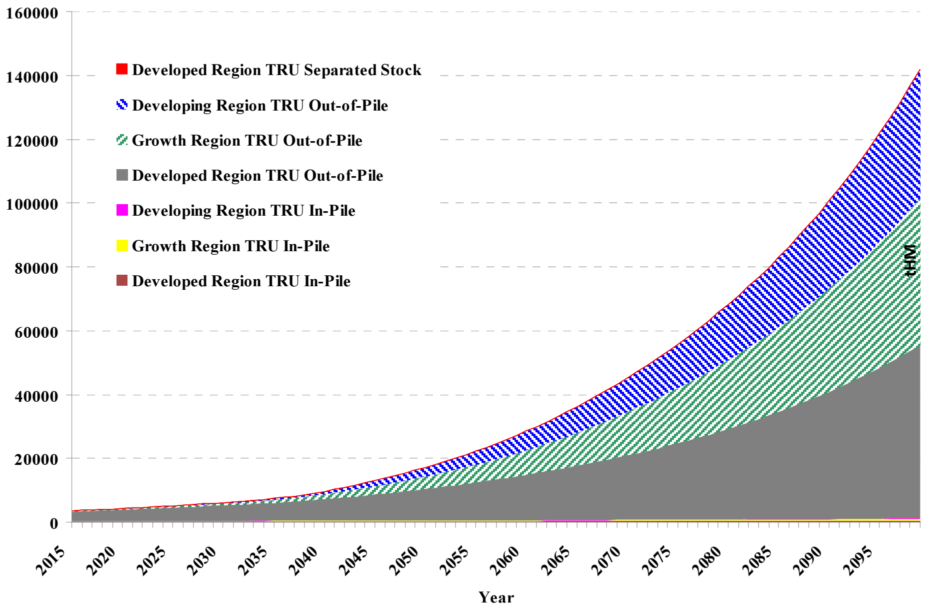
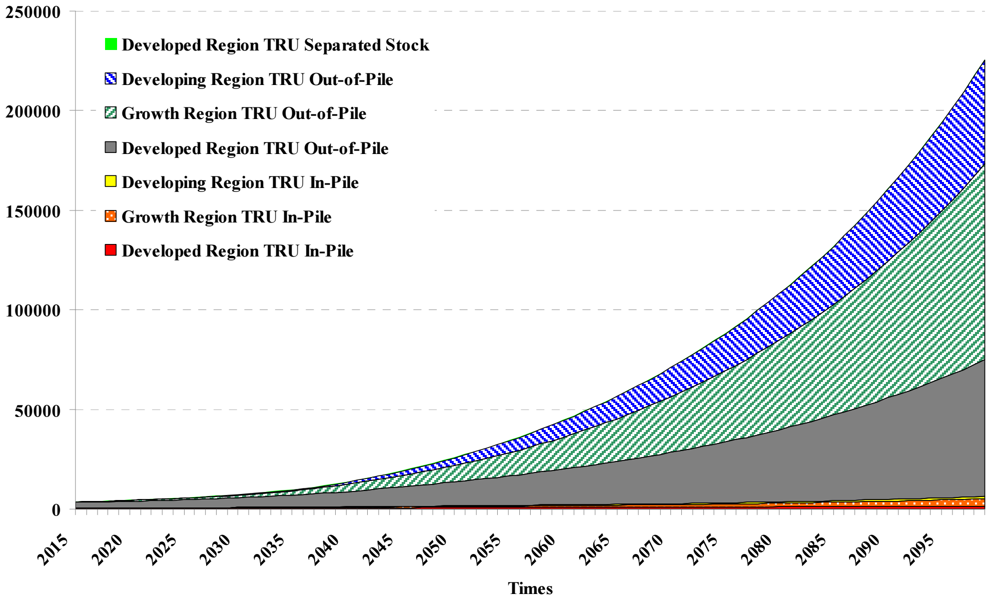
NT.1 No Trade LWR UOX/MOX Deployment TRU Inventories





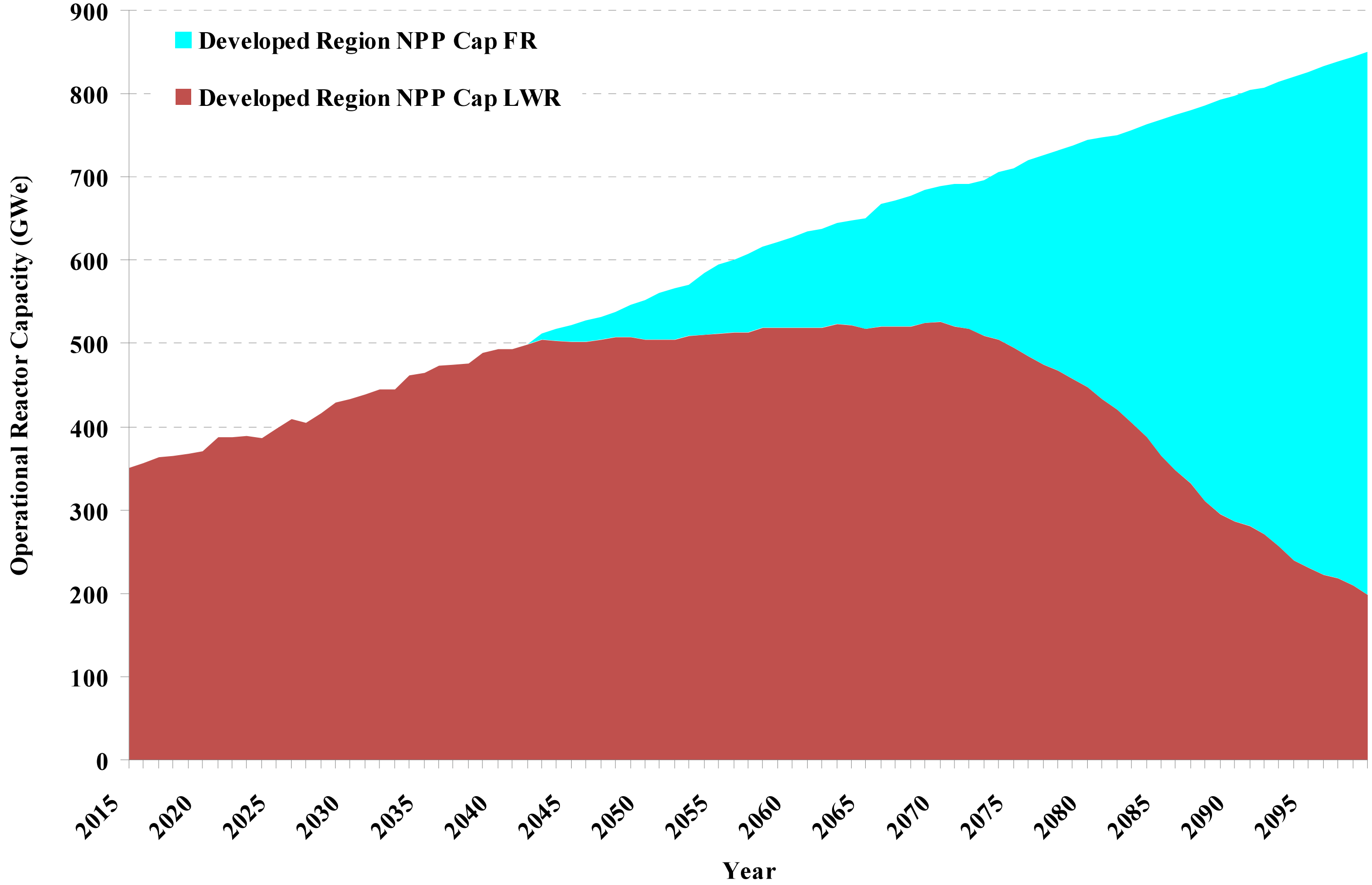
NT.1 No Trade LWR UOX/MOX Deployment

Year 2100		*Developed*	*Growth*	*Developing*
Unat used (tHM)	*Low*	10 115 000	6 936 000	6 908 000
	High	22 510 000	48 092 000	4 773 000
DU-inventory (tHM)	*Low*	9 690 000	6 116 000	6 096 000
	High	20 633 000	42 241 000	4 210 000
Annual Enrichment (SWU/yr)	*Low*	110 000	125 000	125 000
	High	322 000	1 075 000	87 580
SF (tHM)	*Low*	1 111 000	585 000	571 000
	High	2 148 000	3 762 000	393 000
HLW (tHM)	*Low*	2 151	0	0
	High	2 151	0	0

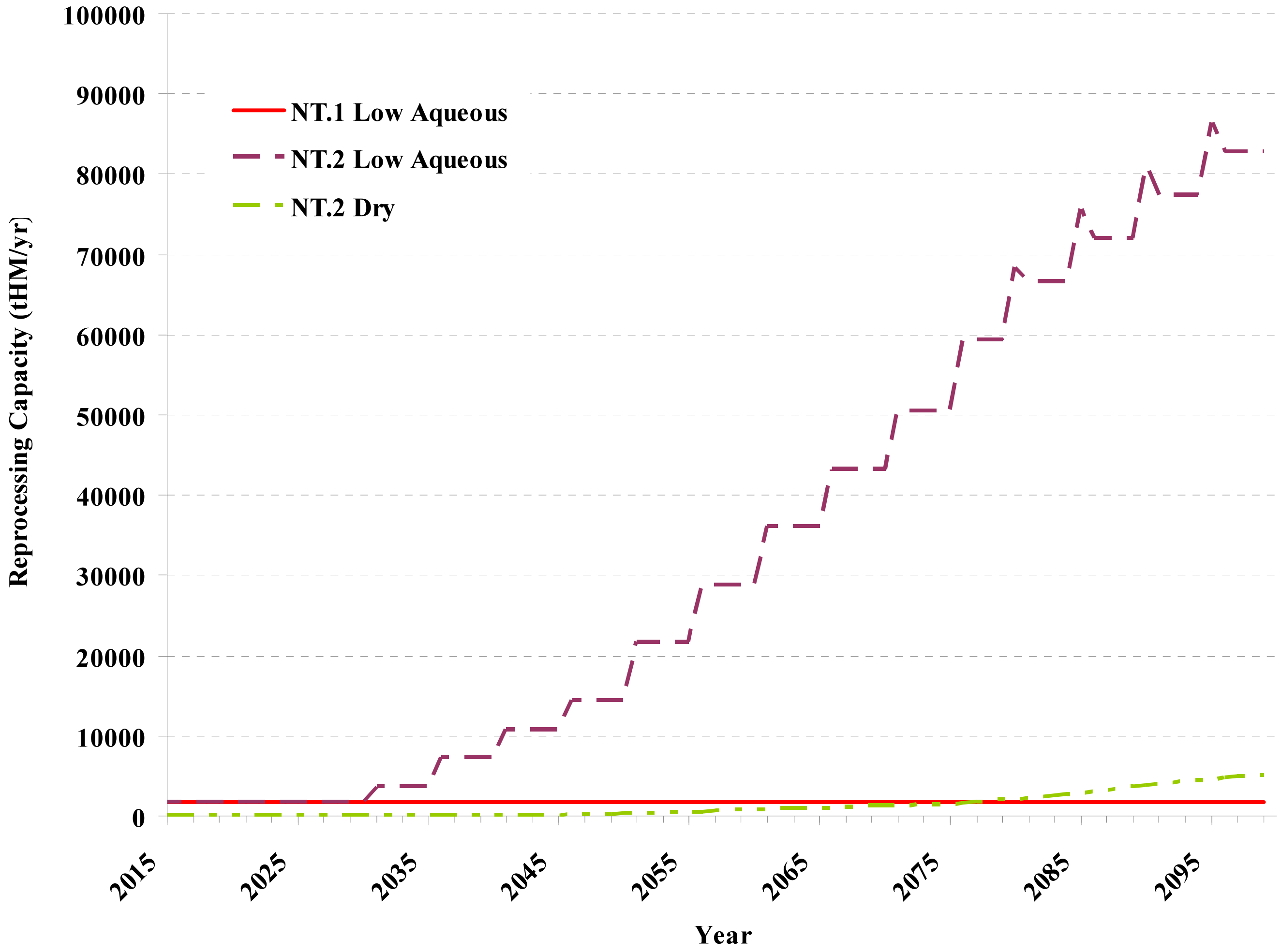
Multi-regional Scenarios Considered in Study

Nuclear Energy System Scenarios		Developed Region	Growth Region	Developing Region
No Trade (NT)	*Scenario NT.1*	LWRs UOX/MOX Low High	LWRs UOX Low High	LWRs UOX Low High
	Scenario NT.2	LWRs UOX/MOX FRbu TRU Repro & Fab Low	LWRs UOX/MOX High	LWRs UOX High
Limited Trade (LT)	*Scenario LT.1*	LWRs UOX/MOX FRbu TRU Repro & Fab Low	LWRs UOX/MOX FRbu High	LWRs UOX High
International Fuel Services (IFS)	*Scenario IFS.1*	LWRs UOX/MOX FRbr TRU Repro & Fab Low	LWRs UOX/MOX STAR-H2 High	LWRs UOX STAR-H2 High

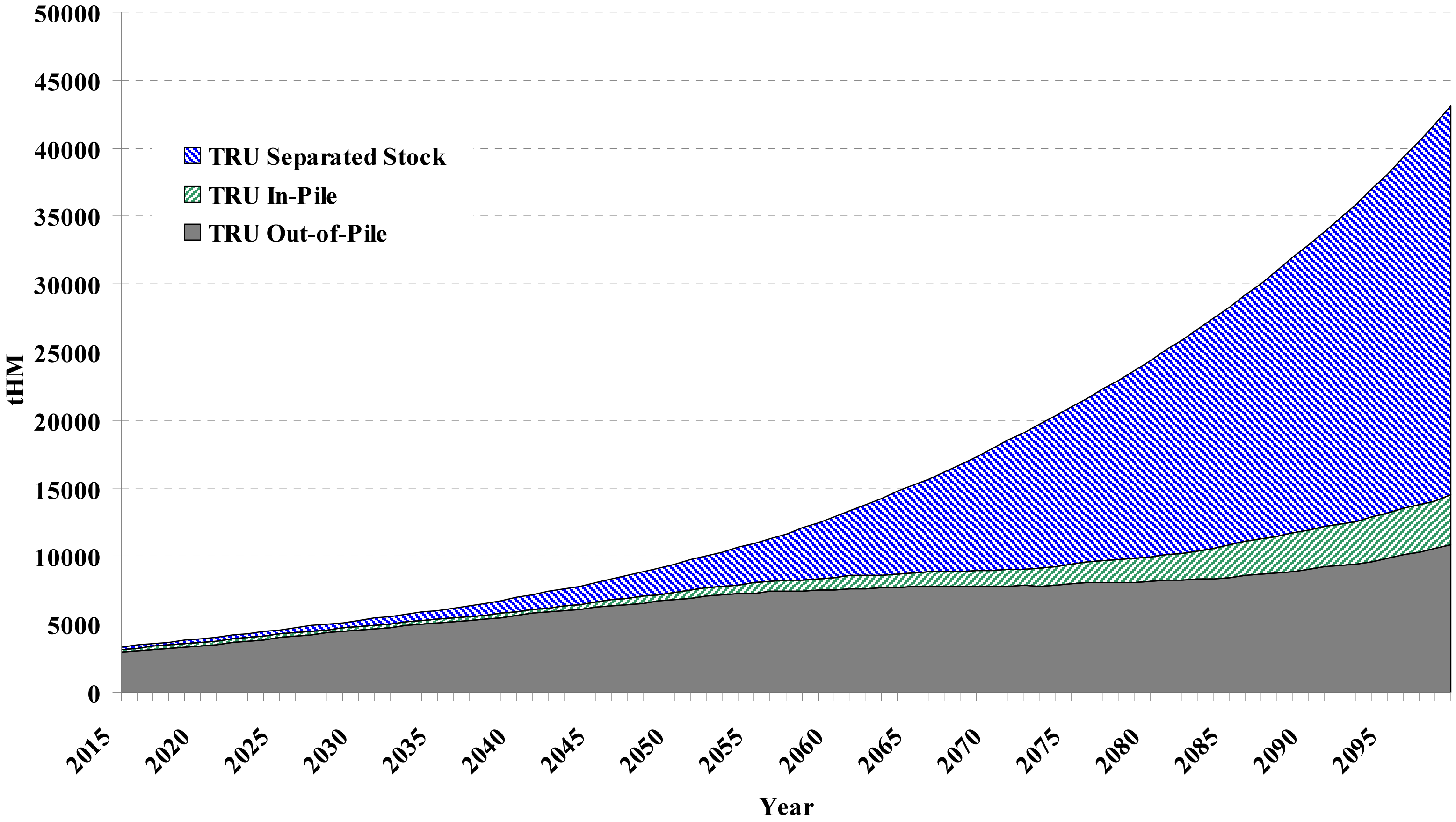
NT.2 No Trade LWR UOX/MOX + FRbu deployment Nuclear Power Park



NT.2 No Trade LWR UOX/MOX + FRbu deployment Reprocessing capacity deployment

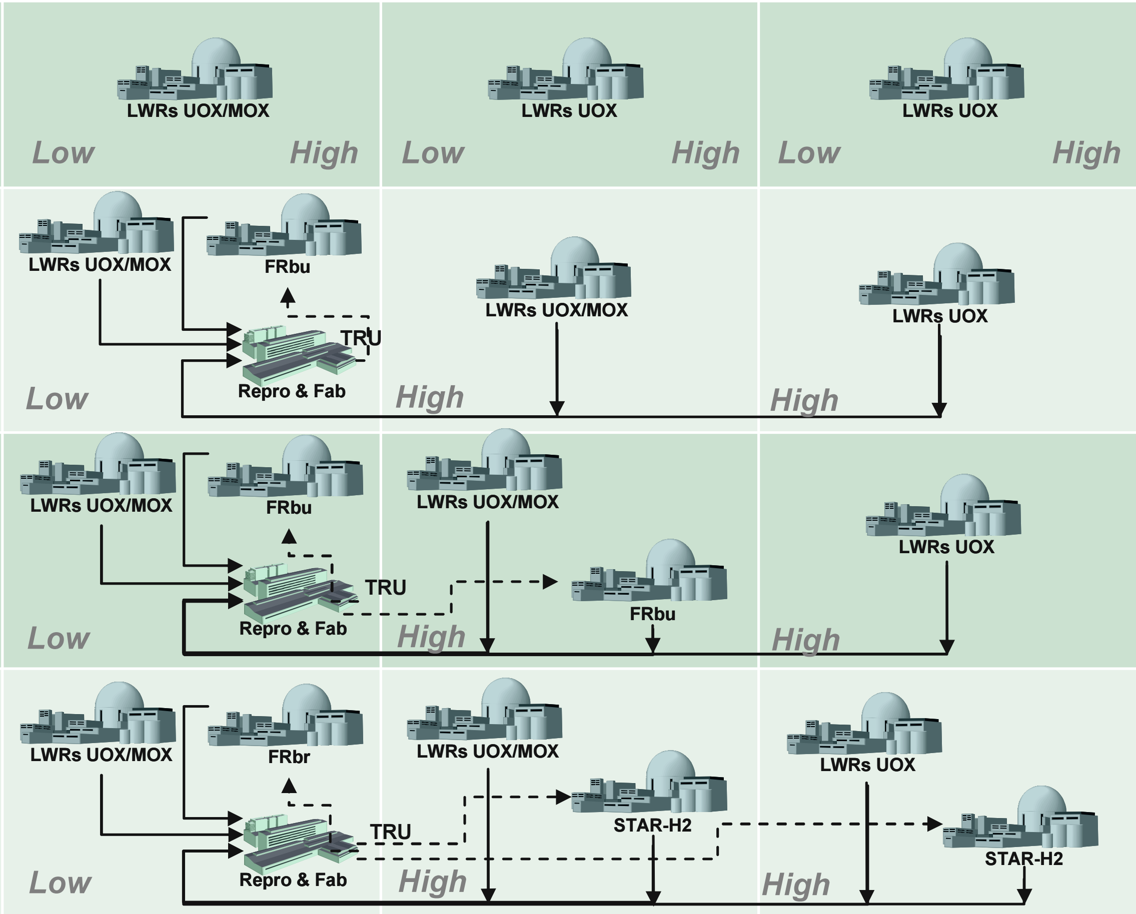


NT.2 No Trade LWR UOX/MOX + FRbu deployment Nuclear Power Park

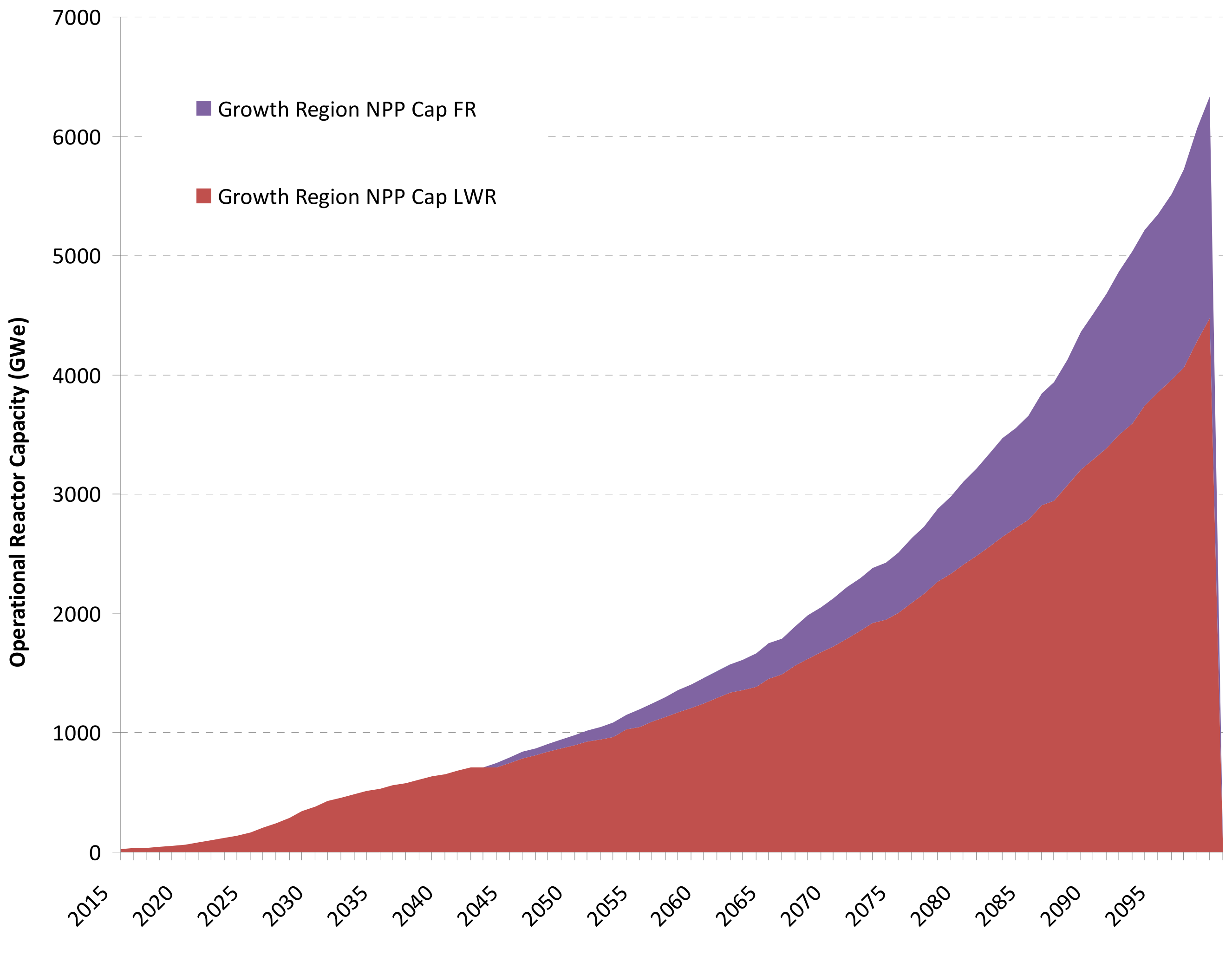


Multi-regional Scenarios Considered in Study

Nuclear Energy System Scenarios		Developed Region	Growth Region	Developing Region
No Trade (NT)	*Scenario NT.1*			
	Scenario NT.2			
Limited Trade (LT)	*Scenario LT.1*			
International Fuel Services (IFS)	*Scenario IFS.1*			



LT.1 Limited Trade
Nuclear Power Park - Growth region for high energy variant



Summary

- A demonstration of possible synergies between nuclear energy deployments in different world regions are presented assuming hypothetical strategies for nuclear systems deployment that involve transitions to FR systems.
- Dynamic simulation of multi-regional nuclear energy deployment scenarios requires a complex analysis tool which has recently become available through an advanced version of the DANESS model.
- Scenarios consider transitions to FR systems with different conversion ratios according to possible forecast nuclear energy futures and strategies for waste minimization and resource sustainability.
- Sustainable nuclear energy deployment worldwide can be investigated taking into account regional effects and synergies between the different regions

BACKUP

Reactor Types Considered

NPP-type	Unit Power (MWe)	Thermal efficiency (%)	Average Load Factor (%)	Fuel use
Gen-II LWR	1000	32	90	UOX45, MOX45
Gen-III LWR	1300	34	90	UOX60, MOX60
FR CR=0.75	1000	40	90	FRbu-fuel
FR CR=1.25	1000	40	90	FRbr-fuel
STAR-H2	178	44.5	95	STAR-H2fuel

Fuel Types Considered

Fuel-type	Average burn-up (GWd/tHM)	Core-management & Cycle length (mo)	Fresh Fuel Composition	Spent Fuel Composition
UOX45	45	1/4th 12	3.7% ^{235}U	94.5% U 1.14% Pu 0.14% MA
MOX45	45	1/4th 12	91.8% U 8.2% Pu	89.5% U 5.75% Pu 0.59% MA
UOX60	60	1/5th 12	4.8% ^{235}U	92.5% U 1.26% Pu 0.18% MA
MOX60	60	1/5th 12	89.9% U 10.07% Pu	86.27% U 6.77% Pu 0.95% MA
FRbu-fuel	99.6	1/5th 7.7	78.8% U 19.5% Pu 1.7% MA	70.5% U 17.78% Pu 1.49% MA
FRbr-fuel	22.13	1/3rd 12	92.6% U 6.5% Pu 0.9% MA	89.65% U 7.74% Pu 0.77% MA
STAR-H2fuel	93	1/1 240	89.1% DU 10.8% Pu 0.1% MA	78% U 10.8% Pu 0.1% MA
Remark: The FR-fuels represent the average fuel characteristics for all fuels used in such FRs, i.e. especially for FRbr-fuel, the fuel characteristics represent the average of driver and blanket fuels.				