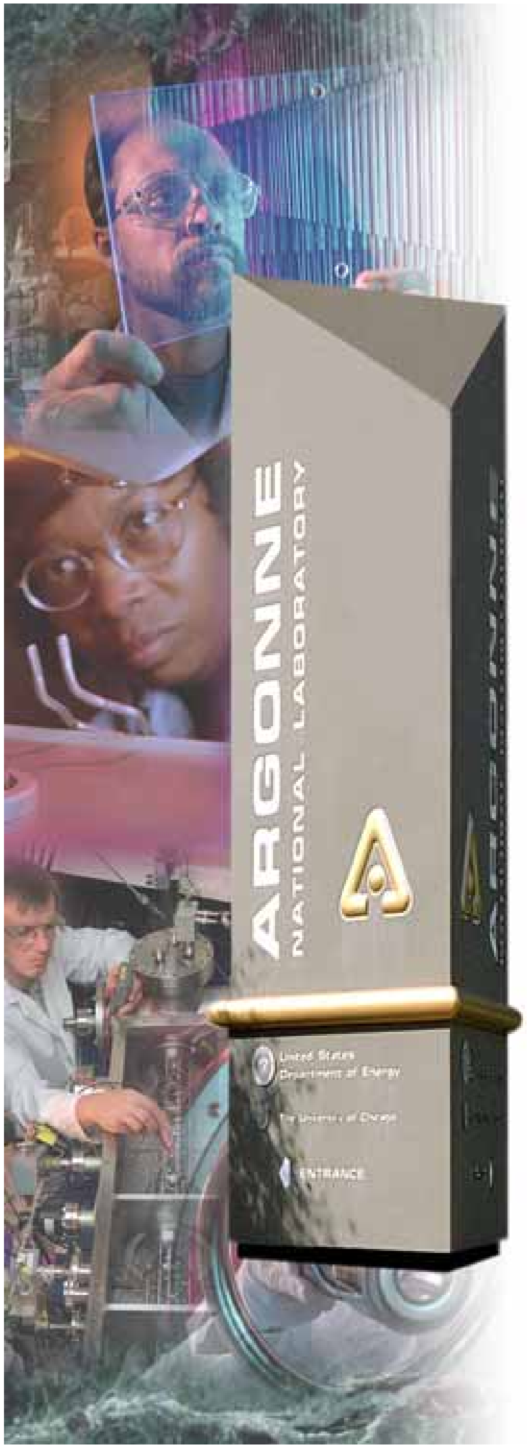

Enabling our Energy Security through the Nuclear Fuel Cycle

DANESS

Dynamic Analysis of Nuclear Energy System Strategies

ANL

July 20-22, 2004

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Overview

- **DANESS**
  - Objective
  - DEMO µ-Manual
- **Scenarios**
  - Initial conditions and assumptions
  - Variables definition

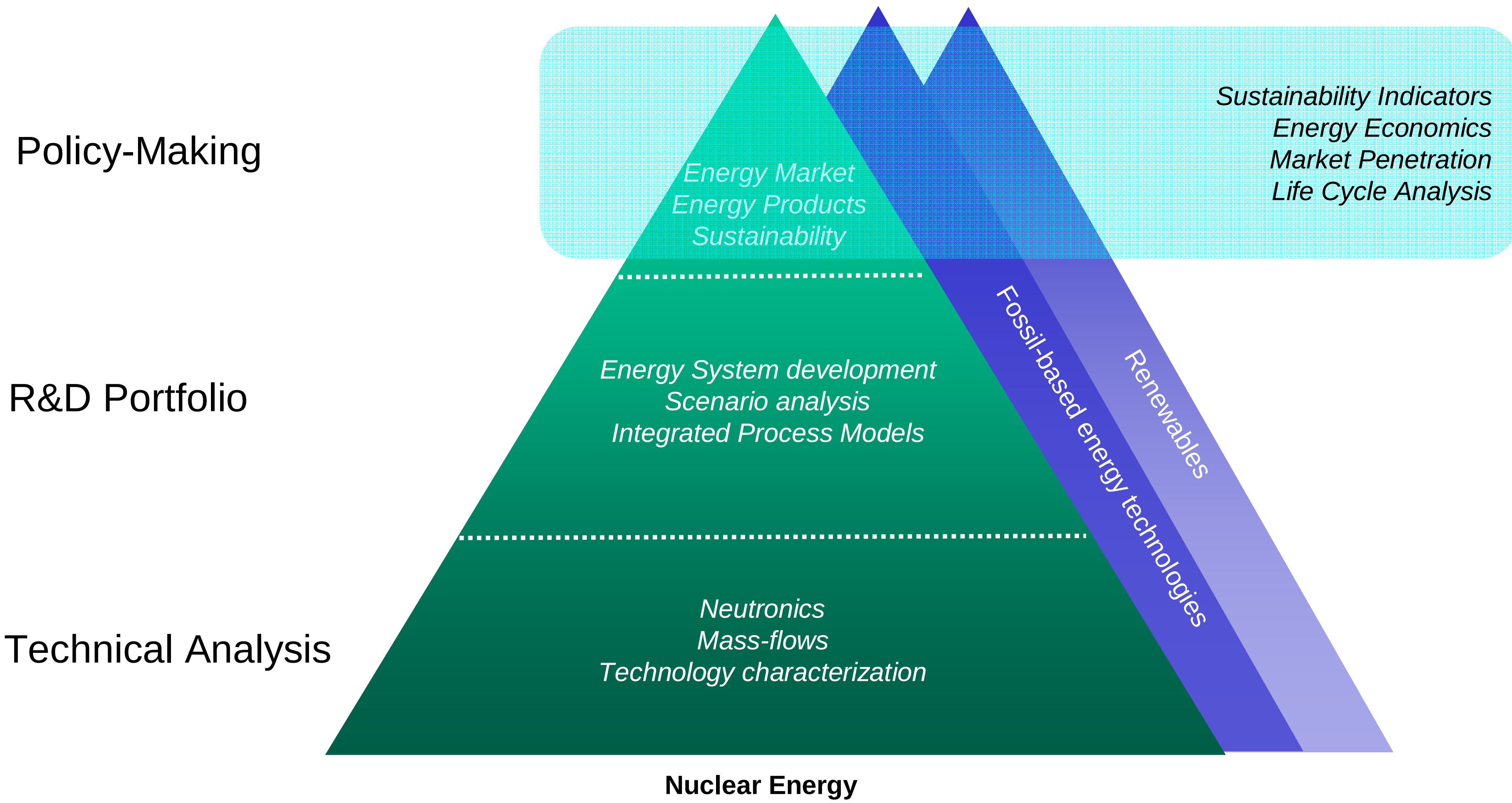
DANESS

- ***Dynamic Analysis of Nuclear Energy System Strategies***

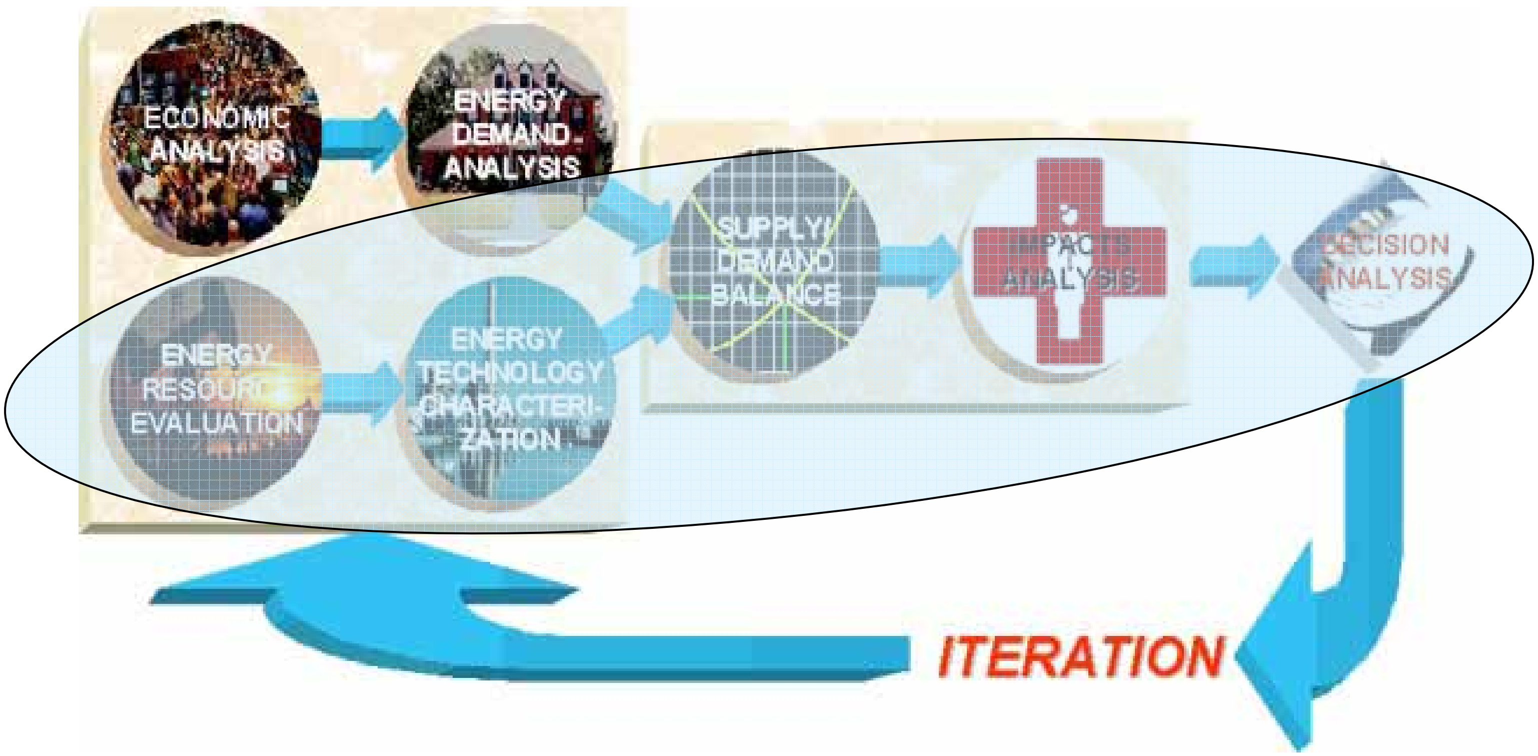
An easy-to-use and quick policy-informing tool
for the
technical-economic assessment
of nuclear energy systems
in a
macro-economic energy development context

  - *Scope:*
    - *Integrated process model of nuclear energy systems*
    - *Integration with other energy model codes*
    - *PC/Mac platform, < 5 min calculation time*
    - *For use by experts, consultants, policy-makers, students, …*
- **More info on <u>www.daness.anl.gov</u>**

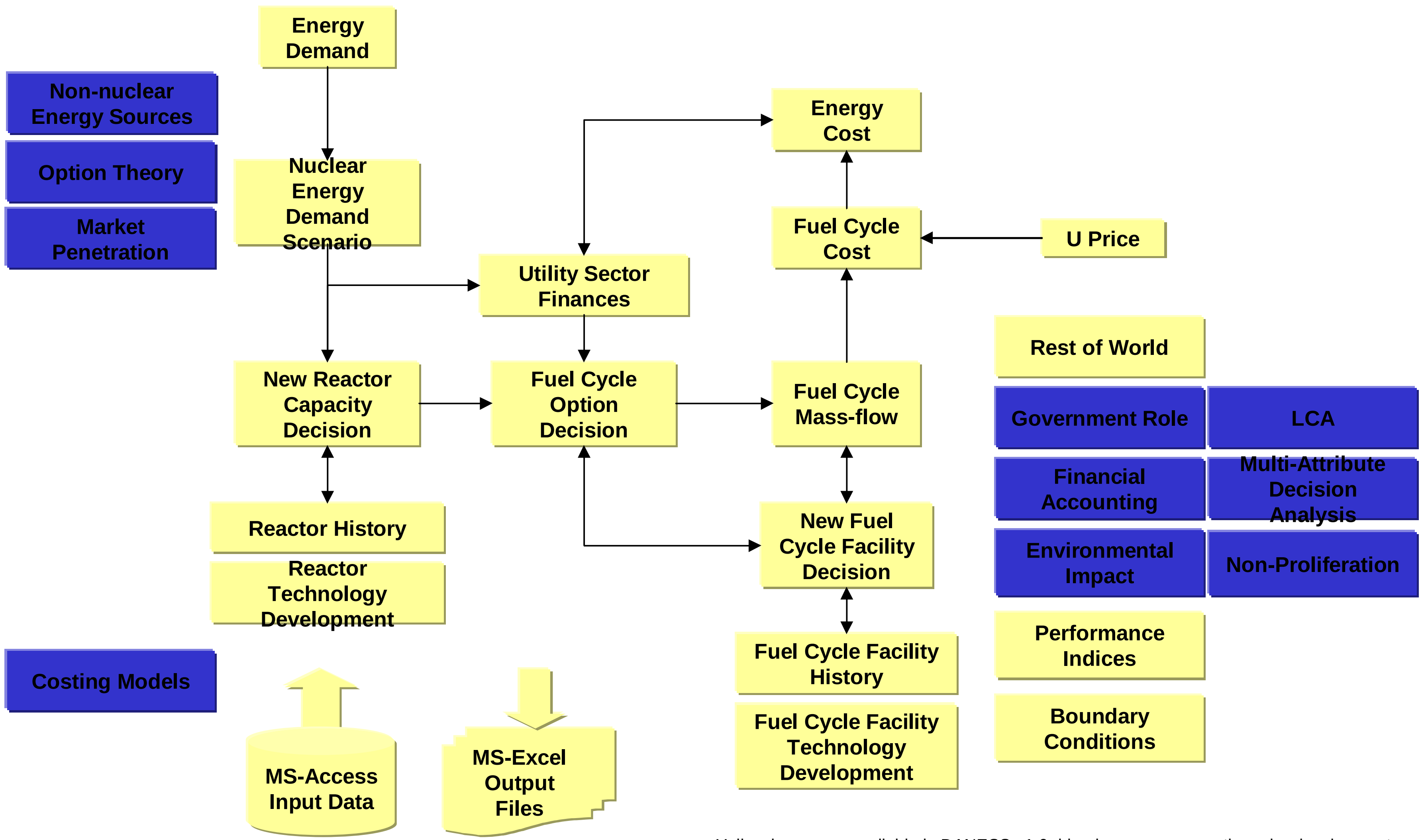
DANESS as policy-informing tool



Today, DANESS© is an Intra-nuclear model



DANESS©



Yellow boxes are available in DANESS v1.0, blue boxes are currently under development

Intended Use

- Analysis of development paths for nuclear energy
- Integrated process model
- Parameter scoping for new designs
- Economic analysis of nuclear energy systems
- Government role
- Educational use

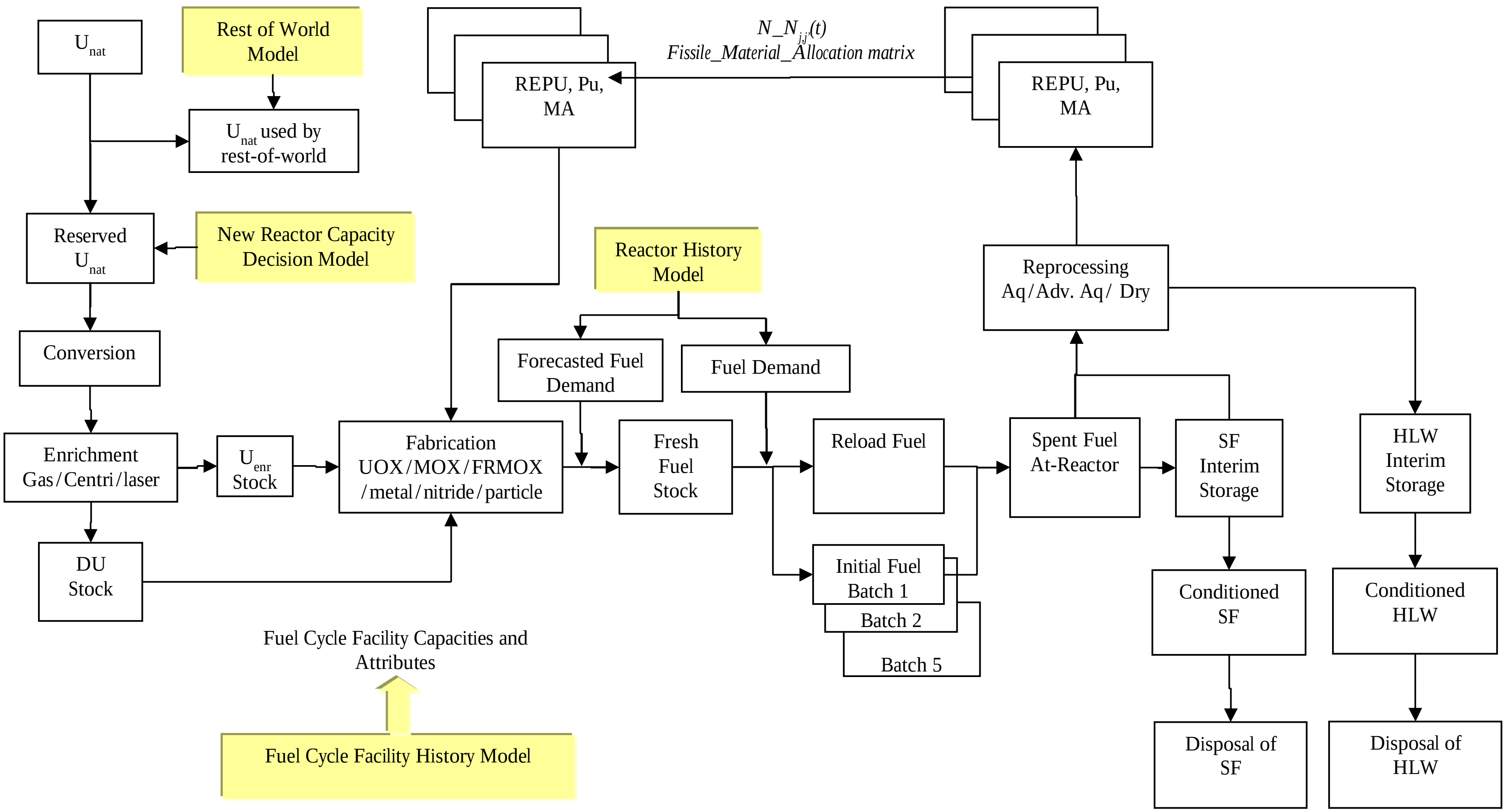
Features

- **Developed using commercial software Ithink (www.hps-inc.com)**
  - Possibly other software environments in nearby future
- **May be web-based**
- **Easy-to-use**
  - ‘Get-to-know’-time: approx. 2 weeks
  - ‘Repeat-to-know’-time: one hour
  - Can be customized / parametrized
- **Supported by database**
  - Attributes Reactors / Fuels / Facilities
  - Allows up-to-date simulations

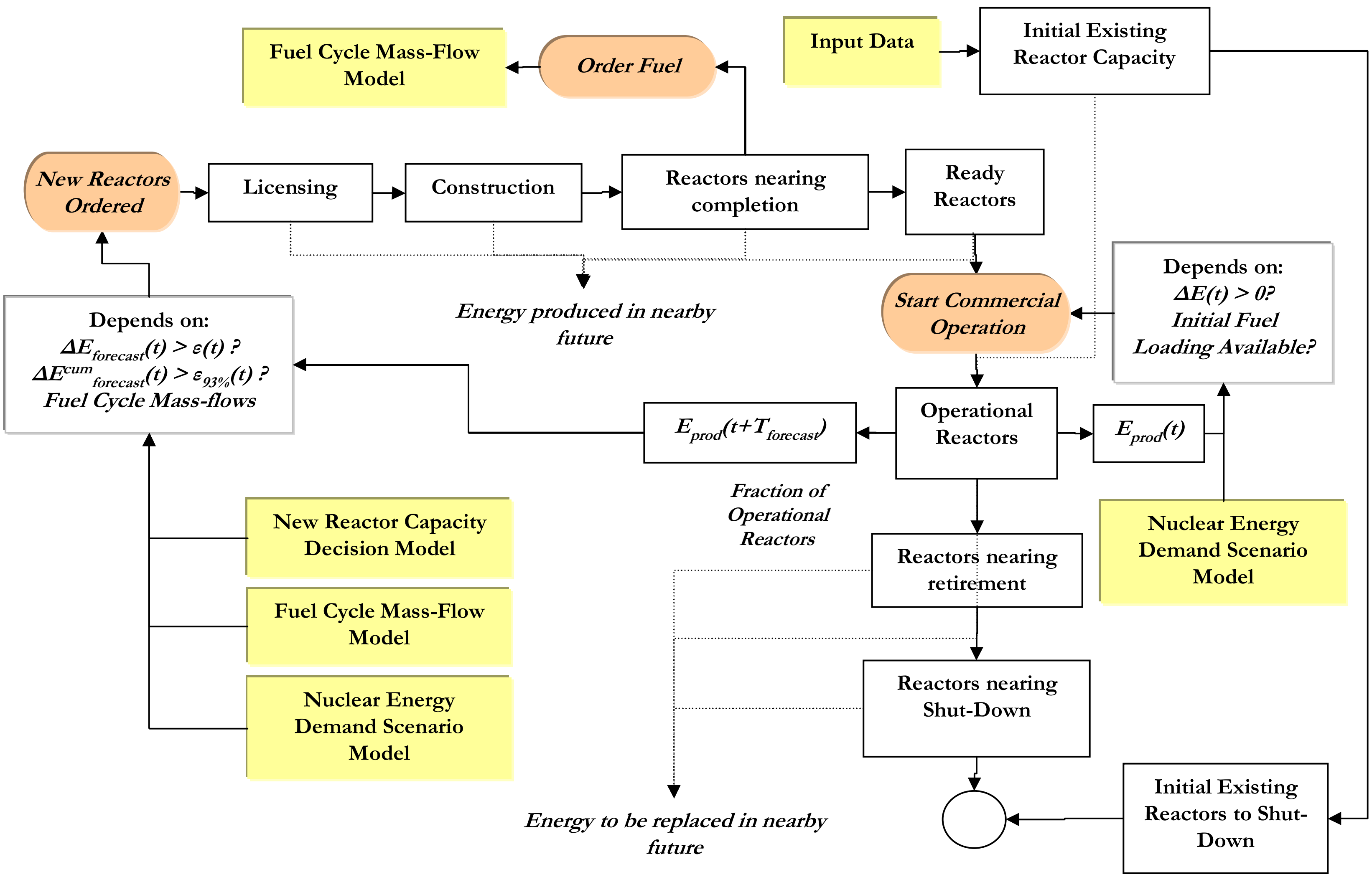
Energy Demand Driven

- **Energy demand driven dynamic analysis of nuclear energy systems**
  - Energy demand by:
    - *World, Region, Country*
    - *According to IIASA/WEC, IAEA/NEA scenarios, user-defined*
- **Initial conditions**
  - Existing reactor park based on IAEA/NEA RDS-1 and Brown Book data (annually updated)
    - *Attribute Database for reactor types (ALWR, ADS, AGR, BWR, FR, GCR, HTGR, HWGCR, HWLWR, LWGR, PHWR, PWR, SGHWR, WWER)*
    - *Attribute Database for fuel cycle materials and fuel cycle facilities*

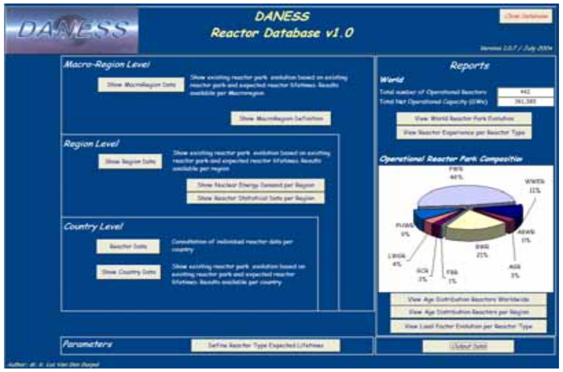
Fuel Cycle Model



Reactors Follow a Life-path



Coupled databases



- **History of existing and planned reactors**
  - Including statistics
  - Annually updated
- **Attributes of reactors, fuels and fuel cycle facilities**
  - Including references
  - Regularly updated
- **Version Management**
  - Keeps track of all changes in DANESS
  - Quality Assurance

DANESS Demo

- **DANESS DEMO is pre-configured for 5 fuel cycle scenarios representative for the USA, i.e.:**
  - Electricity demand and hydrogen demand modelled
    - *Electricity delivered by existing LWRs, new ALWRs and FRs*
    - *Hydrogen delivered by HTGRs*
  - Electricity and hydrogen demand may be varied and follow a exponential growth, defined by input in main menu of DANESS
- **Only limited set of variables are available for output**
  - On-line graphing
  - Output to Excel via table on user interface

Definition of Output Variables (1)

Year		
Edem	TWhe/yr	Electricity Demand
H2 Edem	TWhe/yr	Hydrogen energy demand expressed in equivalent TWhe/yr
Eprod[Electricity]	TWhe/yr	Electricity Produced
Eprod[Hydrogen]	TWhe/yr	Hydrogen Produced expressed in equivalent Twhe/yr
Eprod_Total	TWhe/yr	Total energy produced
Operating_R_Cap[BWR]	GWe	Total operational reactor capacity existing BWRs
Operating_R_Cap[PWR]	GWe	Total operational reactor capacity existing PWRs
Operating_R_Cap[ALWR]	GWe	Total operational reactor capacity ALWRs
Operating_R_Cap[HTGR]	GWe	Total operational reactor capacity HTGRs
Operating_R_Cap[FR]	GWe	Total operational reactor capacity FRs
Reactorunits_being_Constructed[BWR]	#	Number of BWRs being licensed and constructed during each year
Reactorunits_being_Constructed[PWR]	#	Number of PWRs being licensed and constructed during each year
Reactorunits_being_Constructed[ALWR]	#	Number of ALWRs being licensed and constructed during each year
Reactorunits_being_Constructed[HTGR]	#	Number of HTGRs being licensed and constructed during each year
Reactorunits_being_Constructed[FR]	#	Number of FRs being licensed and constructed during each year
Total_Park_Fractions[BWR]	%	BWR-fraction in installed reactor park
Total_Park_Fractions[PWR]	%	PWR-fraction in installed reactor park
Total_Park_Fractions[ALWR]	%	ALWR-fraction in installed reactor park
Total_Park_Fractions[HTGR]	%	HTGR-fraction in installed reactor park
Total_Park_Fractions[FR]	%	FR-fraction in installed reactor park

Definition of Output Variables (2)

Aenr	SWU/yr	Total annual enrichment needs
Afabr_tot	tHM/yr	Total annual fabrication needs
Afabr[UOX]	tHM/yr	Total annual UOX fabrication needs
Afabr[Particle]	tHM/yr	Total annual Particle fuel fabrication needs
Afabr[Metal]	tHM/yr	Total annual Metal fuel fabrication needs
Unat	tHM	Amount of natural uranium reserves left
Uncomitted Unat Reserves	tHM	Amount of natural uranium reserves left assuming natural uranium allocated for total lifetime of reactors
Possible Years US Park Deployment	#	Number of years that US Reactor park might expand before natural uranium reserves would be depleted
Possible Years World Park Deployment	#	Number of years that World Reactor park might expand before natural uranium reserves would be depleted
LifetimeTotal SF in OTC Mode	tHM	Total amount of SF that might need to be disposed of in a once-trhough fuel cycle scenario for all reactors and covering all SF during technical lifetime of reactors
Disposal Sites Used	tHM	Equivalent number of disposal sites needed for the already nonretrievable disposed of SF/HLW
Disposal Sites Potentially Needed	tHM	Equivalent number of disposal sites needed to dispose of actual amount of SF residing in fuel cycle and already in disposal site
Total in Disposal	tHM	Total amount of SF/HLW already disposed of
LifeTime Total Disposal Sites in OTC Mode	tHM	Number of disposal sites needed if all reactors running in once-through mode during total technical lifetime.
Total TRU In Recycling Process	tHM	Total amount of transuranics in recyling in fuel cycle, i.e. In reprocessing, separated material, in fabrication or in fresh fuel stock
Total TRU InPile	tHM	Total amount of transuranics in reactor cores
Total TRU in SF	tHM	Total amount of transuranics in spent fuel not yet disposed of
Total TRU in HLW	tHM	Total amount of transuranics in vitrified waste not yet disposed of
Total TRU in Disposal	tHM	Total amount of transuranics in disposal site (being it in SF or in HLW)

Definition of Output Variables (3)

Unit Facilities Used [EnrGas]	#	Number of unit capacity gaseous diffusion enrichment plants needed
Unit Facilities Used [EnrCentr]	#	Number of unit capacity ultracentrifuge enrichment plants needed
Unit Facilities Used [UOXFab]	#	Number of unit capacity UOX-Fabrication plants needed
Unit Facilities Used [MetalFab]	#	Number of unit capacity Particle Fuel-Fabrication plants needed
Unit Facilities Used [PartFab]	#	Number of unit capacity Metal Fuel-Fabrication plants needed
Unit Facilities Used [ReproAq]	#	Number of unit capacity aqueous reprocessing plants needed
Unit Facilities Used [ReproDry]	#	Number of unit capacity dry reprocessing plants needed
Unit Facilities Used [SFInt]	#	Number of unit capacity SF Interim storage sites needed
Unit Facilities Used [HLWInt]	#	Number of unit capacity HLW Interim storage sites needed
Unit Facilities Used [SFCond]	#	Number of unit capacity SF Conditioning plants needed
Unit Facilities Used [HLWCond]	#	Number of unit capacity HLW Conditioning plants needed
Heat Load Equivalent YM Sites Used	#	Number of Yucca Mountain equivalent sites used by disposed waste taking into account decay heat considerations (references = P-UOX)
Heat Load Equivalent YM Sites Potentially Needed	#	Equivalent number of disposal sites needed to dispose of actual amount of SF residing in fuel cycle and already in disposal site taking into account decay heat considerations (reference = P_UOX)

Remark: Unit capacities are considered ‘typical’ for the respective facilities.

Scenarios

	Electricity Generation	Electricity and Hydrogen Generation
Once-Through Fuel Cycle	***Scenario 1*** **Existing LWRs + new Advanced LWRs**	***Scenario 4*** **Existing LWRs + new Advanced LWRs** **New HTGRs for hydrogen generation**
(Partially) Closed Fuel Cycles	***Scenario 2*** **Existing LWRs + new Advanced LWRs with all UOX-fuel reprocessed** **TRUs to FR for multi-recycle, FR burner with CR=0.25**	***Scenario 5*** **Existing LWRs + new Advanced LWRs with all UOX-fuel reprocessed** **TRUs to FR for multi-recycle, FR burner with CR=1.0** **New HTGRs in once-through mode for hydrogen generation**
	Scenario 3 **Existing LWRs + new Advanced LWRs with all UOX-fuel reprocessed** **TRUs to FR for multi-recycle, FR with CR=1.0**	

Reactor and Fuel Attributes

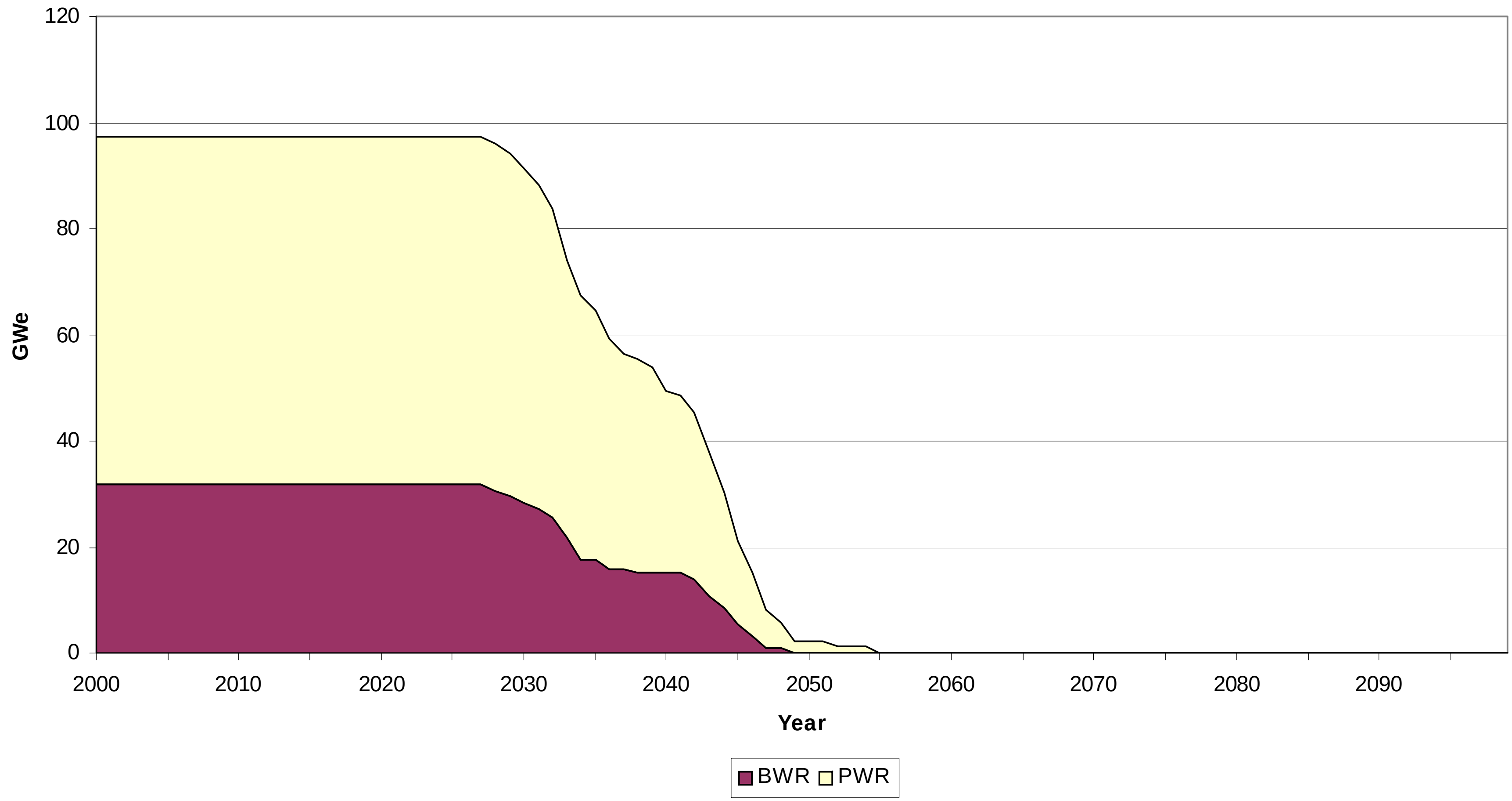
Reactors		Only Elec Production		Only H2 Production	Only Elec Production
Notation	**BWR**	**PWR**	**ALWR**	**HTGR**	**FR**
Initital Capacity (MWe)	**31789**	**65475**	**0**	**0**	**0**
Fuel Use	**(UOX)**	**(UOX)**	**UOX**	**Particle**	**Metal**
Thermal Power (MWth)	**2647**	**2647**	**2647**	**268**	**842**
Electric Power (MWe)	**900**	**950**	**1000**	**110**	**320**
Thermal Efficiency (%)	**34**	**34**	**34**	**41**	**38**
Capacity Factor (%)	**90**	**90**	**90**	**90**	**90**
Fuel cycle length (mo)	**12**	**12**	**12**	**18**	**12**
# fuel batches	**5**	**5**	**5**	**3**	**7**
Technical Lifetime (yr)	**60**	**60**	**60**	**60**	**60**

Fuels						
Notation	**B_UOX** **BWR-UOX**	**P_UOX** **PWR/ALWR-UOX**	**A_UOX** **PWR/ALWR-UOX**	**Particle** **HTGR Particles**	**Metal1** **FR-Fuel** **CR=0.25**	**Metal2** **FR-Fuel** **CR=1.0**
Average BU (GWd/tHM)	**40**	**50**	**50**	**80**	**200**	**120**
Initial U (t/tIHM)	**1**	**1**	**1**	**1**	**0**	**0**
Initial U enrichment (%)	**3,7**	**4,2**	**4,2**	**8.1**		
Initial DU (t/tIHM)	**0**	**0**	**0**	**0**	**0,0395**	**0,655**
Initital REPU (t/tIHM)	**0**	**0**	**0**	**0**	**0,3305**	**0**
Initial Pu (t/tIHM)	**0**	**0**	**0**	**0**	**0,519**	**0,304**
Initial Np (t/tIHM)	**0**	**0**	**0**	**0**		
Initial MA (t/tIHM)	**0**	**0**	**0**	**0**	**0,1117**	**0,041**
Spent U (t/tIHM)	**0,94576**	**0,93545**	**0,93545**	**0.9029**	**0,3305**	**0,594**
Spent U enrichment (%)	**0,8**	**0,82**	**0,82**	**2.3**		
Spent Pu (t/tIHM)	**0,01085**	**0,012**	**0,012**	**0.0137**	**0,3769**	**0,248**
Spent Np (t/tIHM)						
Spent MA (t/tIHM)	**0,00114**	**0,00125**	**0,00125**	**0.00103**	**0,0897**	**0,034**
Spent FP (t/tIHM)	**0,04225**	**0,0513**	**0,0513**	**0.082**	**0,2029**	**0,125**

Assumptions

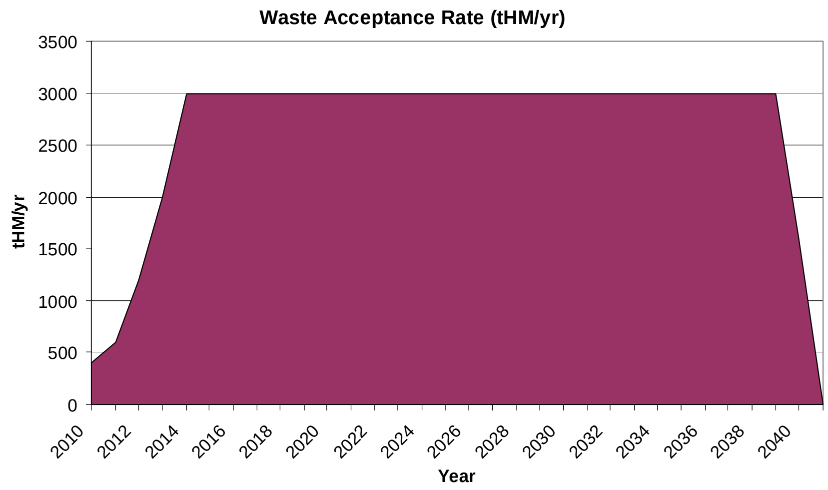
- **Initial Reactor Park**
  - BWRs/PWRs as currently operating in US reactor park
  - Technical lifetime assumed = 60 years
    - *ShutDown profile of reactors, see next slide*
  - SF amount residing in fuel cycle in year 2000
    - *BWR UOX*
      - 7508 tHM in interim SF storage
      - 6953 tHM in At-Reactor storage ponds
    - *PWR UOX*
      - 11864 tHM in interim SF Storage
      - 13743 tHM in At-Reactor storage ponds
    - *Makes total of 40068 tHM SF present in the year 2000*

ShutDown of Existing LWRs



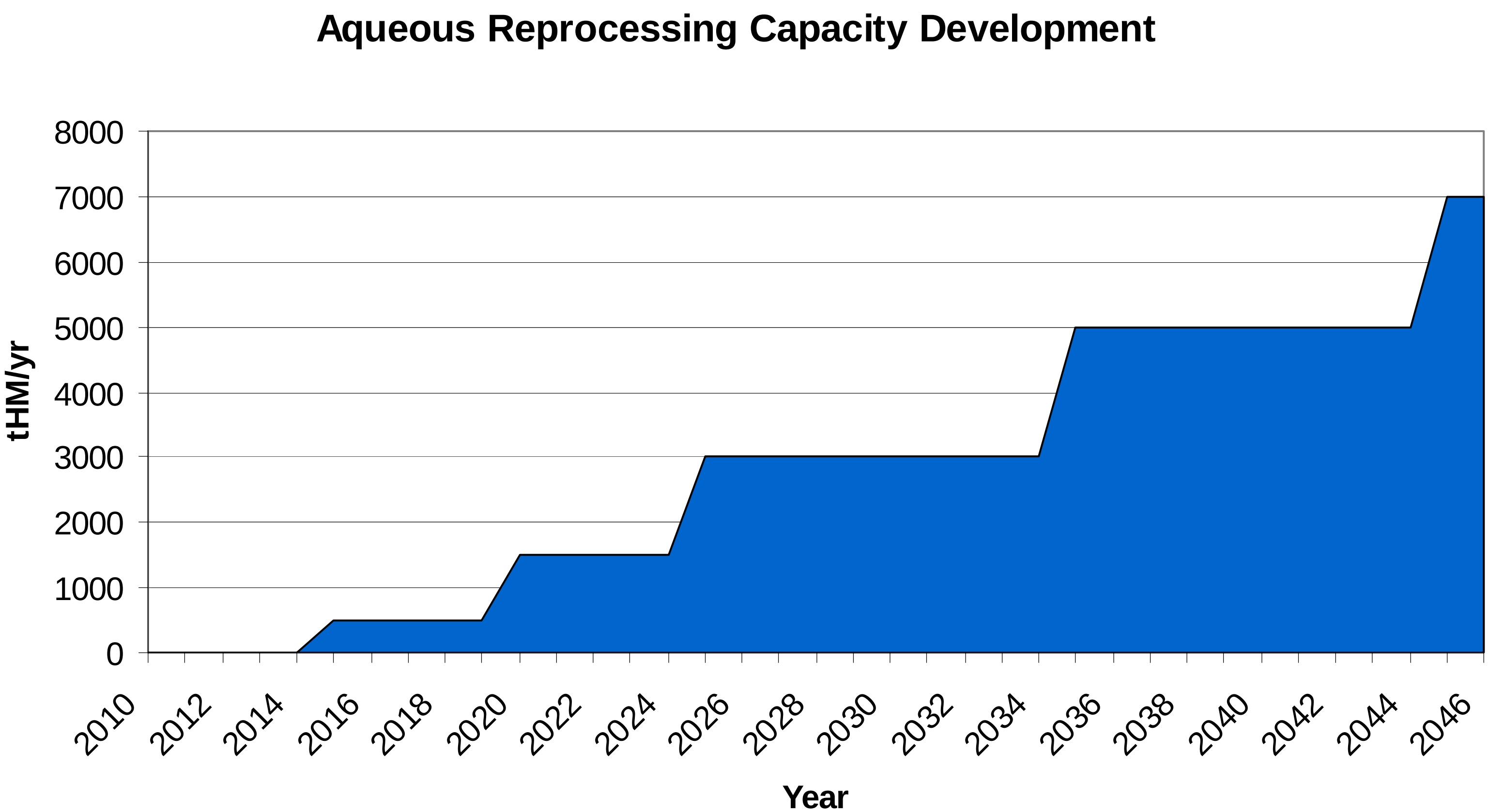
Assumptions

- **'Unlimited' fuel cycle facilities available, except for reprocessing and SF conditioning capacity**
  - 'Unlimited' means that no limitations in capacity availability will occur for front- and back-end facilities
  - SF-conditioning
    - *Yucca Mountain's SF-conditioning or waste acceptance rate is assumed*



    - *Aqueous reprocessing: capacity is developed as shown in next slide*

Aqueous Reprocessing Capacity Development



After 2050: 'Unlimited' Aqueous reprocessing capacity, i.e. available capacity as needed

This deployment schedule may be shifted in time, i.e. between -5 and + 30 years, by using the slider in the DANESS graphical user interface

Capacity, Timings and Losses in fuel cycle

Facility	Unit Capacity	Transit Time	Losses (%)		
	tHM or tHM/yr or tSWU/yr	years	U	TRU	FP
Conversion	1000	1	1	-	-
Enrichment	1000	1	0.1	-	-
Fabrication					
UOX	250	1	0.1	-	-
Particle	250	1	0.1	-	-
Metal	50	1	0.1	0.1	-
SF At-Reactor Storage					
UOX	1000	10	0	0	0
Particle	1000	2	0	0	0
Metal	1000	2	0	0	0
Reprocessing					
Aqueous	500	1	0.2	0.2	100
Dry	50	0.5	0.2	0.2	100
SF Interim Storage	10 000	20	0	0	0
HLW Interirm Storage	50	10	0	0	0
SF Conditioning	400	2	0	0	0
HLW Conditioning	50	10	0	0	0

Remarks

- **DANESS DEMO has been parametrized:**
  - To minimize the separated TRU-stock in the fuel cycle while guaranteeing the continued operation of FRs for at least 6 years before shortage of TRU might occur
    - *i.e. Smaller TRU-inventories may be sought but this may demand the premature shut-down of FRs due to shortage of TRUs.*
  - No economic decision making is used. Requested reactor park fractions are pre-set in DANESS DEMO.

Assumptions

- **Energy demand**
  - World Nuclear Energy demand
    - *Initial = 2574 TWhe/yr*
    - *Exponential growth as defined for US, i.e. same annual growth rate and start of growth*
      - Default assumed 2%/yr growth
  - Hydrogen demand may be set in user interface
    - *Default set*
      - 5%/yr growth starting from 60 TWhe/yr in US from the year 2010 on
- **Natural Uranium resources**
  - KCR = 4 MtU
  - KCR + RAR = 7 MtU
  - KCR + RAR + EAR = 15 MtU (default)