Generation IV Concept Summary – Cover Page

STAR-H2: The Secure Transportable Autonomous Reactor for Hydrogen (Electricity and Potable Water) Production

NERI Project No: 2000-0060

Concept Category:	**Metal-cooled reactors**
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1.0 STAR-H2 Technical Summary

1.1 Overview of Reactor Plant and Energy Converters

The Secure Transportable Autonomous Reactor for Hydrogen production, STAR-H2, is a Pb-cooled, fast neutron spectrum, 400 MW_{th} modular-sized reactor. It is a low power density natural circulation cooled reactor with passive load following and passive safety response characteristics. The 400 MW_{th} sizing retains natural circulation capability in a rail shippable reactor vessel size as well as allowing for RVACs passive decay heat removal. The reactor operates on a 15 year whole core cassette refueling interval using uranium/transuranic nitride fuel.

The reactor heat source at 780°C core outlet temperature drives a thermo-chemical water cracking plant for hydrogen and oxygen production for revenue sales and a desalinization bottoming cycle for production of potable water feedstock for the hydrogen production and for revenue from water sales. The hydrogen is produced as a synthetic chemical energy carrier for revenue in the overall primary energy market, and for the *distributed* electrical energy production market, but a fraction of production can optionally be used for peak load electricity production onsite – using either a hydrogen/oxygen combustion gas turbogenerator or using a fuel cell/inverter. Relatively high temperature process heat (550°C) can be supplied as an option. Figure 1 illustrates the plant concept – where a helium intermediate loop carries the heat energy from the Pb-cooled nuclear heat source to the chemical balance of plant.

1.2 Overview of Fuel Cycle

STAR-H2 is designed to be fissile self sufficient with an internal core conversion ratio of one. The fuel cycle is based on nonaqueous (electrometallurgical) recycle and remote (vibropack) refabrication of the uranium/transuranic nitride fuel. The recycle technology produces a commixed stream of all transuranies and achieves incomplete fission product removal such that the transuranic materials during processing and during fresh and used cassette shipping are always at least as unattractive for weapons use as LWR spent fuel.

The fuel cycle feedstock is natural or depleted uranium and the multi recycle through sequential cassette reload cycles achieves total fission consumption of the feedstock; only fission product waste forms go to a geologic repository.

It is expected that all fuel cycle operations (front and back end) are performed at a consortia-owned Regional Fuel Cycle Support Center operating under international oversight and that all fuel cassette shipments and used cassette returns are conducted by Regional Center personnel.

1.3 Overview of the Expected Market Conditions and The STAR-H2 Market Niche

The STAR-H2 Gen-4 concept is tailored for energy market conditions predicted for the 2030's and beyond. Economic projections forecast that by the time of Gen-4 deployment in the 2030's, the worldwide installed capacity of nuclear power will be in the range of 2000 GW_e – up by a factor of six from current deployment; that the nuclear capacity additions in developing economies will be occurring at up to twice the rate of those in industrialized economies; that dwindling ore reserves will motivate fuel recycling; that hydrogen will have already achieved a significant market share among chemical energy carriers (oil, gas, and coal), and that potable water will be in short supply in many world regions and especially in the bludgeoning megacities of developing and developed countries alike. STAR-H2 is intended to extend nuclear's role beyond electricity alone, into the non-electric two thirds of the primary energy market via production of hydrogen as a synthetic chemical energy carrier and to profitably employ waste heat for production of potable water.

The STAR-H2 Gen-4 concept is targeted for two categories of clients – utility clients in those developing countries expecting to make *small incremental capacity additions* to their initially-spare energy services supply infrastructure and to *merchant plant* clients in industrialized countries who wish to enter broadened energy service markets which are dependent on hydrogen as an energy carrier. Both category of clients can be foreseen to benefit from shared infrastructure exploitation based on grid delivery of electricity, hydrogen, potable water, and communications *through a common grid of easements* and for *distributed electricity generation architectures*.

While large monolithic plants will continue to hold electric market share, the STAR-H2 concept approach rests on an assumption that the small plant market size (hundreds to thousands of modular plants) and extent (deployment in developed and developing economies) will create a sufficient niche to induce supplier strategies based on factory fabrication/rapid site installation of plant modules. Additionally, it is assumed that institutional innovations will have been successfully emplaced to facilitate widespread global nuclear energy deployment on the basis of regional front and back end fuel cycle support centers which rely on economy of scale for bulk actinide handling and waste management. They will be consortia-owned and will operate under international oversight to service hundreds to thousands of regional clients in nations having no interest in or no ability to deploy an indigenous fuel cycle infrastructure.

1.4 Descriptive Details

The Reactor

The reactor layout (Fig. 2) is identical to that of STAR-LM except that Pb to He IHX modules replace the invessel steam generator modules of STAR-LM. The reactor operates at low power density and achieves 100% natural circulation cooling; passive load following; passive safety performance; and 15 year cassette reloading interval.

The 780°C Pb coolant service conditions are new relative to STAR-LM. The fuel is TRU-nitride – known to be compatible with Pb and expected to be pyro recycleable and vibropac remote fabricable. The materials (cladding, core support structures and vessel) for use in these high-temperature Pb, long refueling interval service conditions are not yet settled. We are evaluating Nb-1Zr, and composites of SiC and ZrC – the latter of which open the potential for composite-based innovations in factory serial fabrication.

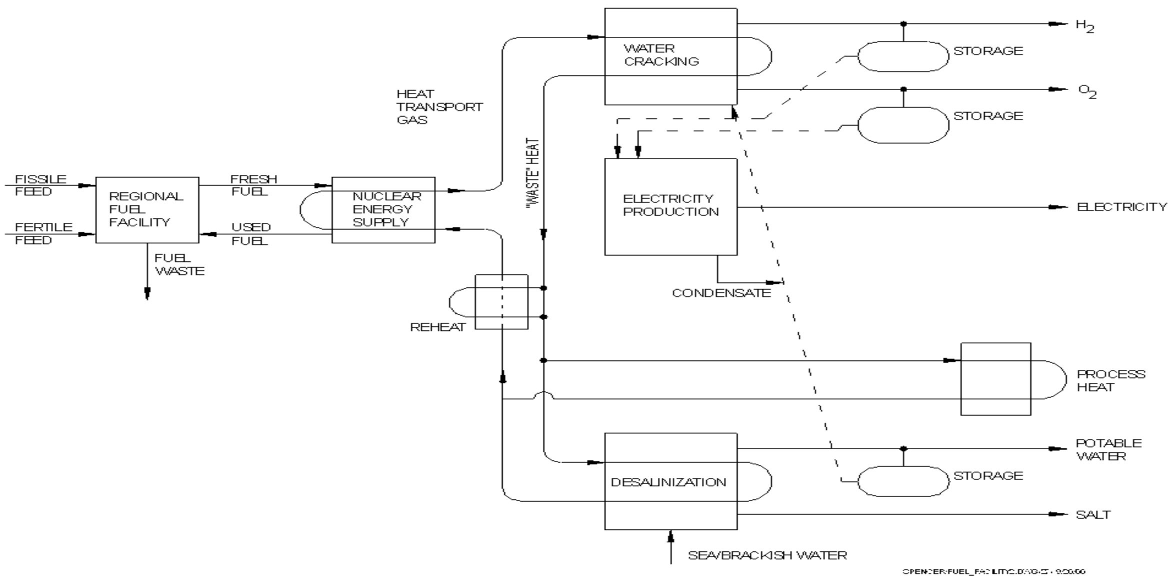

Fig. 1. Integration of Elements of the Nuclear- and Hydrogen-based Energy

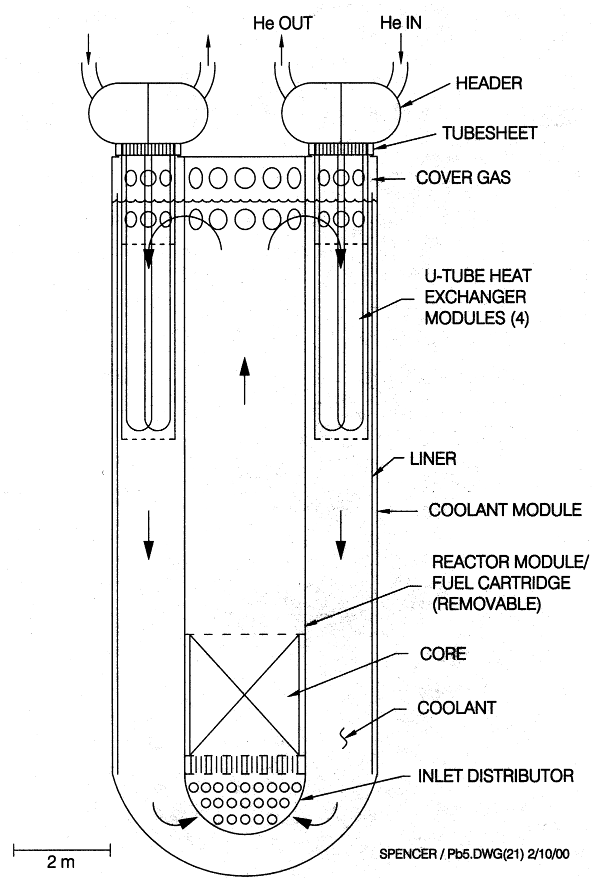

Fig. 2. Modularized, Natural Circulation Reactor Concept for the Nuclear Heat Source With Modular-Invessel He Heat Exchanger

The Water Cracking Plant

We have settled on the UT-3 four step process which is based on Br, Ca, and Fe based reagents with solid/gas reactions and separations (Fig. 3). Nuclear heat is supplied at 700-750°C through an intermediate He loop which decouples the nuclear and chemical safety issues. Water and heat enter the thermochemical plant and H_2 and O_2 are produced; at a practical conversion efficiency of ~45% in the Japanese design. The reagents are regenerated in two of the four steps and are recirculated. Modifications of UT-3 to a simpler three step process which might dramatically raise the practical efficiency are under evaluation. The UT-3 technology has been demonstrated at the bench scale in Japan and a prototype scale design has been used for cost estimating by Japanese developers.

- 4-Step Thermochemical Cycle

		Temp (°C)	Heat Flow	Purpose 1.
	$CaBr_2$ (s) + H_2O (g) ® CaO(s) + 2HBr(g)	700-750	in	Crack water with $CaBr_2$ and heat
2.	CaO(s) + Br_2 (g) ® $CaBr_2$(s) + ½ O_2(g)	500-600	~ neutral	Regenerate $CaBr_2$ using Br_2
3.	Fe_3O_4(s) + 8H Br(g) ® 3Fe Br_2(s) + 4H_2O(g) +Br_2(g)	200-300	out	Regenerate Br_2 using rust
4.	3$FeBr_2$(s) + 4H_2O(g) ® Fe_3O_4(s) + 6HBr(g) + H_2(g)	550-600	in	Regenerate rust using water & heat

- H_2 released in Step 4: O_2 released in Step 2
- Heat Supplied at ~725°C in Step 1 and at ~575°C in Step 4

Status

- For STAR-H_2, a heat balance (Modeling with ASPEN code) in progress
- Process simplifications are under evaluation

Fig. 3. UT-3 Process for Cracking Water

The Desalinization Plant

Desalinization will utilize waste heat from the water cracking and hotel load steam turbine equipment at 125°C and below – using the Multi-Stage Flash "off the shelf" industrialized technology. Developments in Reverse Osmosis will be monitored (and if adopted would free up the low grade waste heat for other applications).

Electrical Hotel Load and Heat Rejection

A steam turbine will be used to harvest reject heat (at ~550°C) from the water cracking plant and will supply the electrical hotel load needed for pumping reagents in the water cracking plant, for circulating brine and water in the desalinization plant, and for pressurizing the H_2 and O_2 products for distribution. The brine will be the final heat rejection path from the cascaded thermodynamic cycles.

The Optional On-Site $H_2 + O_2$ To Electricity Energy Converters

The fundamental purpose of the plant is to service the primary energy market with a synthetic chemical energy carrier (H_2) – which will also service a *distributed* electricity production infrastructure based on microturbines and fuel cells. The plant will run base loaded to produce H_2, O_2, and potable water, with storage onsite to buffer variations of demand.

Optional onsite energy converters – H_2/O_2 combustion turbogenerators or fuel cells – are being evaluated for onsite peaker plant electricity producers. The turbogenerator is based on a modification of a Westinghouse design for a "near term" plant combusting H_2 with O_2 to produce 1600°C, 300 bar supercritical steam driving high pressure, intermediate pressure and low pressure turbines on a common generator shaft. The Westinghouse design achieves ~71% conversion efficiency. The modification for STAR-H2 involves removing the low pressure turbine and potentially using the heat recovery steam generator for top off heating of the He on its way to the UT-3 plant. The high and intermediate pressure turbogenerators are of modular size and low staffing requirement typical of combustion gas turbines and they achieve ~65% conversion efficiency. For small grids in developing countries, market conditions may favor centralized energy production with dinural load following by the onsite combustion turbine – achieving an overall conversion efficiency of nuclear heat to electricity via hydrogen of 29% = .45 x .65 or higher if the UT3 efficiency improvements work out. Obviously, where higher efficiency monolithic electricity producers are possible, the STAR-H2 would be a peaker only.

Alternately, a bank of stationary fuel cells and alternators could be used for onsite electricity production. This option has not yet been evaluated.

In either case, the products of onsite energy conversion are alternating electricity and water; the water will rejoin the feedwater to the water cracking plant.

The Fuel Cycle Operations

Front and backend fuel cycle operations will be conducted at large regional fuel cycle support centers operated by consortia under international oversight. Fuel recycle will be based on nonaqueous processes which carry all transuranics in a commixed product stream. Fuel pin refabrication will be done remotely owing to the high radiation levels caused by the higher actinides in the fuel composition. Fresh core cassettes will be assembled and shipped by Regional Center carrier to the client's plant and (using equipment brought with the fresh cassette) the 15-year spent cassette will be changed out for the fresh one. The spent cassette will be carried back to the Regional Center for recycle/refab operations.

Fission product waste forms will be fabricated at the Regional Center, and waste disposal will be conducted by the Regional Center.

The fuel is currently envisioned to be uranium/transuranic nitride; the recycle technology to be electrorefining; and the refabrication to be vibrocompaction. If a higher melting point metallic alloy of uranium/transuranics can be developed, the recycle and refabrication technologies will revert to the ANL electrorefining/injection casting processes which are at a more complete state of development.

The low power density and high specific loading (kg TRU/kw), of STAR-LM and the need to achieve zero burnup control swing to allow for passive load following (and operating staff reduction) preclude its use as an effective breeder or burner. Once deployed, it will run *fissile self sufficient* with depleted (or natural) *uranium feedstock* as the only requirement for cassette refueling. The initial cassette working inventory will be derived from LWR spent fuel at the regional fuel cycle center. In the very long term, a growing deployment of STAR-LM module plants will draw initial working inventory from excess fissile production in fast breeder reactors.

2.0 Potential of the STAR-H2 Concept for Meeting the Generation-4 Goals

2.1 Sustainability

The goals of the proposed concept are to achieve an expanded role for nuclear energy; to extend the applicability of the non carbon emitting fission resource into the non-electric two-thirds of the primary energy market; and to provide a sustainable global energy supply architecture with fission generated heat coupled to modern energy converters (gas turbines and fuel cells) that will already be in widespread use in the decades following 2020. The architecture will employ dual energy carriers (electricity and hydrogen) which avoid reliance on economy of scale, and are suitable for modularization and deployment in developing as well as developed economies and which achieve very high conversion efficiency of energy resource to end use. Potable water and other process heat energy products will be generated in addition. The high degree of safety is intended to make the plant sitable near megacities to provide population energy services and additionally to meet needs for carbon-free industrial process heat.

The water cracking for hydrogen production process is integrated with electricity and potable water manufacture and tied to a fast neutron spectrum reactor specifically to provide for *long term* energy sustainability – achieving both intergenerational equity and interregional equity on the basis of an ecologically neutral cycle of a carbon free chemical energy carrier ($H_2O \rightarrow H_2 \rightarrow H_2O$), no competition for potable water, and using only plentiful natural or depleted uranium feedstock sufficient for several millennia of world energy supply capability.

Resource Utilization

The fast spectrum reactor and nonaqueous recycle technology will achieve essentially 100% conversion of uranium resources into heat – providing a multi-millemia energy supply by fully exploiting the potential of the earth's endowment of uranium ore. If uranium can later be extracted from the oceans, the duration extends to tens of millennia.

2.1.1 Waste Management

Complete fission consumption of the uranium feedstock by means of multi recycle of transuranics in the fast spectrum reactor produces a waste stream comprised only of fission products (and trace losses of transuranics from the recycle step). The short lived fission products, while highly radiotoxic at reactor discharge, decay to levels below that of the original uranium ore within 300 years. The long lived fission products never exceed the toxicity of the original ore. Both classes of fission products are fabricated into robust waste forms for geologic sequesterization for the several century decay period.

US energy use per capita is 9 tonnes of oil equivalent/year. If provided by fission, the waste mass of fission products would not exceed a third of an ounce per capita per year; even accounting for the inert waste form stabilizing matrix this is a far cry from 9 tonnes of CO_2 and ash. After three centuries of fission product sequesterization the transformation of uranium $\rightarrow$ energy and fission products is ecologically neutral with the toxicity of ore converted to an *equivalent* toxicity of long-lived fission products.

Hydrogen as an energy carrier is capable to fill all functions of fossil chemical energy carriers in the transportation (fuel cells), process heat, and home appliance primary energy markets which today comprise 2/3 of the 9 tonnes per capita per year of primary energy usage. Hydrogen as a synthetic chemical energy carrier is forecast to achieve dominant market share of chemical energy carriers over the next century and to be significant already by 2030. The use of nuclear generated heat for carbon-free hydrogen production via water cracking can ultimately supplant CH_4 reforming for hydrogen manufacture and will thereby avoid greenhouse gas emissions at the source as well as at the utilization links the energy supply chain. The hydrogen combustion product, water, recirculates via regular channels of the ecosphere – an ecologically neutral energy delivery cycle.

2.1.2 Proliferation Resistance

The concept is based on 15 year cassette refueling of modular reactors from a regional front and back end fuel cycle support center operating under international oversight. The reactor design incorporates no provision for accessing the fuel during the cassette lifetime. The cassette is a single assembly from which individual fuel rods cannot be removed. The vessel upper closure head has no rotating plugs through which a mechanism could be inserted to remove fuel. The module incorporates no fuel handling machinery; at the end of the cassette lifetime the entire core cassette is removed by the regional support center personnel and replaced with a fresh cassette filled with highly radioactive fuel; the used cassette is transported back to the regional support facility for processing.

The regional support facility performs all bulk fissile handling operations including reprocessing, refabrication, cassette loading, waste form production and geologic waste disposal. The recycle is based on nonaqueous methods producing a commixed transuranic product of high radioactivity. It is remotely refabricated and reloaded into replacement cassettes. All processing steps and all shipments are of materials at least as unattractive for weapons use as LWR spent fuel. No transuranics[1] end up in the waste stream or geologic repository.

This architecture was chosen to assure a high degree of resistance to weapons proliferation while at the same time allowing for widespread deployment of modules worldwide. It rests on an assumption that institutional innovations can be put into place in 30 years to allow module clients to benefit from such service centers – *under condition that they conform to a set of international norms on safety, radiological hazards, nonproliferation and safeguards, liability, early notification of accidents, etc.*

2.2 Safety and Reliability

2.2.1 Safe Operation

The STAR-H2 employs the passive safety strategy developed for the Integral Fast Reactor. A low pressure system and double walled vessel eliminates loss of coolant vulnerabilities. A large thermal inertia, large margins from operating to damage temperatures and passive decay heat removal channels eliminate loss of decay heat removal vulnerabilities. Passive self regulation which innately matches heat production to heat removal via reactivity feedbacks, – when coupled with design for zero burnup reactivity loss – eliminates reactivity insertion and station blackout vulnerabilities. Natural circulation cooling at full power eliminates pumping loss vulnerabilities.

The balance of plant is assigned no safety function and passive load following achieved via reactivity feedbacks in response to heat demand communicated only by means the helium intermediate loop totally decouples reactor safety performance from equipment failures and plant operator or plant maintenance personnel mistakes in the balance of plant.

Open pitch of the fuel pin lattice helps avoid blockages. Chemical compatibility of fuel and coolant allows for run beyond cladding breach. Dramatic margin exists between coolant operating point (780°C) and boiling point (~1700°C). Seismic isolation reduces inertial loads which might affect operation of thermostructural reactivity feedbacks. Helium bubble entrainment and core entry upon loss of IHX tube integrity cannot overcome the inertial impedance of the long Pb column from IHX to core entry. Disrupted fuel floats in the coolant and disperses radially at the coolant/covergas interface, avoiding recriticality.

2.2.2 Reliable Operation

Long refueling interval and production of storable products (H2, O2, Water) facilitates base loading with infrequent power level adjustments; this also allows for the achievement of *very high* capacity factors irrespective of electrical grid size. Infrequent load changes, large safety margins and plant simplification (no primary pumps, no refueling equipment) along with passive load following (simplified control system) and no safety functions assigned to the balance of plant reduces complexity and scale of overall plant operations. Modern energy converters (fuel cells and H_2/O_2 combustion turbogenerators) reduce scale and complexity of balance of plant operations.

[1] Trace losses only.

Specialty support teams from the Regional Fuel Cycle Support Center and remote monitoring via satellite improve cost effectiveness and reliability of specialty maintenance tasks.

2.2.3 Investment Protection

The plant is designed at low power density and large operating margins with natural circulation cooling, innate load following, and passive safety for high reliability and forgiving robustness with respect to balance of plant failures or operator/maintenance personnel mistakes.

The reactor is a low pressure vessel filled with a low chemical potential coolant – explosions and fire hazards are low for the reactor itself. The chemical plant, where explosive chemicals are handled, and industrial hazards exist is *decoupled from the reactor* by distance and by the helium intermediate heat transport circuit; since the reactor innately adjusts its power production to any heat demand communicated through the He circuit, – intended or spurious – events in the industrial chemical plant do not influence reactor safety performance.

The modular sizing puts a cap on capital outlay. The long refueling interval provides long term fuel supply security.

2.2.4 Elimination of Need for Emergency Response

The STAR-H2 safety strategy described in Section 2.2.1 is adapted from that used for the IFR – which was demonstrated in full scale tests at the EBR-II sixty-two MW_{th} power plant in 1986 tests; Loss of Heat Sink without scram and Loss of Flow without scram both from full power as well as run beyond cladding breach were all demonstrated to yield benign results. The Level 1 PRA conducted for EBR-II showed that probability of tech spec violation with marginal loss of fuel pin lifetime came in at a slightly lower frequency (<10-6/y) than the probability for core disruption and overall loss of the reactor for the PWR PRA's reported in Wash 1150.

2.3 Economics

2.3.1 Competitive Life Cycle Cost

In order to achieve 15 year refueling interval within demonstrated fuel burnup capability, the STAR-H2 power density is derated relative to sodium-cooled LMFBR's – down to a level comparable to HTGR's. The strategy to overcome this economic penalty of derating vis-à-vis standard LMFBR's is to reduce capital cost by simplification (no primary pumps, no refueling equipment); to rely on factory fabrication of hundreds of serial units with short durations for site installation, to assign no safety function to balance of plant equipment – thereby reducing its construction costs, and to go to more modern, simpler, and cheaper balance of plant equipment as compared with Rankine steam cycle technology.

The strategy for operating cost reduction is to achieve ultra high capacity factor by refueling infrequently and base loading the plant – producing storable products and to diversify the market of energy services offered to provide options for redirecting energy use to exploit shifting profit margins and prices. Also, to employ equipment elimination and passive load following to reduce staffing levels; to assign no safety functions to the balance of plant and use modern energy converters to reduce BOP maintenance and operations staffing levels, and to employ specialty teams from the Regional Support Center to reduce specialty maintenance skill requirements of site staff and improve cost effectiveness.

The strategy for fuel cost reduction is to cap escalation of ore prices by 100% utilization of the uranium energy content, to employ economy of scale for bulk fuel fabrication, processing, and waste management operations at Regional Fuel Cycle support Centers – servicing hundreds to thousands of regional module operators, and to minimize waste stewardship costs by reducing the stewardship duration to several centuries, and by reducing mass and volume of the waste to that of fission product waste forms alone – making more efficient use of the repository volume and operations staff.

2.3.2 Financial Risk

In the energy supply market forecast for the 2030's and beyond it is expected that supplier/buyer risk apportionment in the nuclear energy business will have reversed from that of the 1970's – 80's situation where the buyer bore the dominant risk in the purchase of customized monolithic plants. In the 2030's, as discussed above, there is expected to be a large market share for standardized modular plants produced by suppliers who have invested large sums of capital in factories for serial production of many hundreds of modules. Moreover, the lifetime operations of a client's plants will be supported by consortia who have invested in very large scale regional fuel cycle service centers operating under international oversight. In this situation the supplier/client risk allocation is akin to that in the automobile, airplane or petroleum industries – the client bears lesser risk and receives a commodity product; the supplier bears a substantial risk in having emplaced factories and infrastructure – but reaps substantial returns from a huge and growing commodity market.

In the case of STAR-H2 a further risk reduction occurs for the plant buyer because he diversifies his product offerings to encompass the entire energy services marketplace – *and* he transfers the capital and operating costs of the energy converter assets *to his customers* in a distributed energy service delivery infrastructure which is based on distributed ownership of fuel cell vehicles, district or building microturbines and fuel cells, etc.

3.0 Status of Technology and Technology Needs for the Concept

The STAR-H2 concept is at an early stage of design development (a NERI-00 grant). However, we have adapted its safety strategy and its fuel cycle and waste management strategies from the ten years of development for the Integral Fast Reactor. Furthermore, we have adapted the reactor structural, refueling, neutronics, and thermal hydraulics design approaches from the STAR-LM project – which has a 2-year head start in design effort relative to STAR-H2.

The salient new reactor design features of STAR-H2 relative to STAR-LM are materials related – choice and qualification of cladding and structural materials for 780°C service conditions in Pb and the fabrication technologies for the low-cost serial factory fabrication of reactor modules and of refueling cassettes.

Three safety-relevant issues require more work. Potential for degradation of cooling capacity by sludge buildup in the event of loss of control of coolant chemistry and/or by coolant solidification in the event of local system cooldown (327°C Pb freezing temperature) need to be addressed. The phenomenology and consequences of nitride fuel dissociation under high temperature accident conditions must be understood; on the one hand it may provide a fuel dispersal/HCDA quenching mechanism; on the other it might produce significant reactor tank overpressurization.

The non-aqueous recycle technology for the tentatively selected nitride fuel, while under development at JAERI in Japan is not as well advanced as for metallic alloy, nor is its Russian-developed virbropac remote fabrication technology as available in the West as is the case for the Argonne developed remote casting fabrication used for metallic alloy. Development and prototype testing of these technologies and resulting waste forms is needed. A fuels irradiation test program is required and a fast spectrum fuels irradiation test facility is needed.

The development of the thermochemical water cracking process must be taken beyond the bench scale which has been achieved in Japan. Potentially significant and cost effective modifications have been identified and must be researched starting at the bench scale.

The H_2/O_2 combustion turbogenerator or the fuel cell, while under development by others, (Westinghouse) have not yet reached the prototype state of development. The 500 MW_e H_2/O_2 combustion gas turbogenerator has been characterized by Westinghouse as "near term" (5 years development needed). Large scale stationary fuel cells are only at the several Megawatt scale currently.

A capital cost containment strategy based on simplification, component elimination, serial factory fabrication and rapid site assembly has been devised. And an operating cost containment strategy based on ultra high capacity factor, ultra high energy conversion efficiency, product diversification and operating staff reductions based on simplification, passive load following, and passive safety and elimination of components has been devised. However whether these strategies can overcome the economic penalty of derating power density to achieve 15 year refueling interval will not be determinable until after substantial further engineering refinement of the concept is completed.

4.0 Listing of Additional Materials Transmitted With This Summary

1. Table 1 400 MW_{th} STAR-H2 Design Conditions.
2. Paper: The STAR-H2 Description:
   Spencer, et al, "A Proposed Modular-Sized Integrated Nuclear and Hydrogen – Based Energy Supply/Carrier System," Proceedings of the OECD-NEA 1st Information Exchange Meeting on the Nuclear Production of Hydrogen, Paris, France, Oct. 2-3, 2000 to be published by the OECD.
3. Papers: 21st Century Energy Market Analysis and Market Penetration Strategy
   (a) D.C. Wade, 21st Century Energy Sustainability – Nuclear's Role," Proceedings of the IAEA Advisory Group Meeting – Contribution of Advanced Reactors for Sustainable Development, Vienna Austria, June 12-16, 2000, to be published by the IAEA.

(b) D. C. Wade and D. J. Hill, “Requirements For Fission Energy Supply Infrastructures of the 21^{st} Century – A Systems Viewpoint,” Proceedings of the International Conference on Future Nuclear Systems, Global ’99 – “Nuclear Technology – Bridging the Millennia,” Jackson Hole, WY, August 20 – September 3, 1999.

Table 1. 400 MWt STAR-H2 Design Conditions

Core Thermal Power, MWt	400
Coolant	Pb
Core Diameter, m	2.5
Core Active (Heated) Zone Height, m	1.99
Fission Gas Plenum Height, m	0.50
Total Core (Frictional) Height, m	2.49
Fuel Rod/Cladding Outer Diameter, cm (in)	1.905 (0.75)
Fuel Rod Triangular Pitch-to-Diameter Ratio	1.50
Cladding Thickness, cm (in)	0.10 (0.0394)
Fuel Material	(92%U-8%Pu)N
Fuel Smeared Density	0.78
Fuel Porosity	0
Fuel Pellet Diameter, cm (in)	1.51 (0.593)
Cladding-Fuel Pellet Gap Thickness, cm (in)	0.0996 (0.0392)
Gap Bond Material	LBE
Core Hydraulic Diameter, cm (in)	2.82 (1.11)
Number of Spacer Grids in Core	3
Core-Wide Fuel Volume Fraction	0.252
Core-Wide Cladding Volume Fraction	0.0802
Core-Wide Bond Volume Fraction	0.0710
Core-Wide Coolant Volume Fraction	0.597
Core Fuel Mass, Kg	35300
Core Uranium Mass, Kg	33300
Core Flow Area, m^2	2.93
Number of Fuel Rods	6940
Number of Support and Flow Distributor Plates Below Core	2
Plate Open Area Fraction	0.6
Core Coolant-to-Fuel Rod Volume Ratio	1.48
Core Specific Power of Uranium, KW/Kg	12.0
Core Power per Volume, MW/liter	0.0409
Core Mean Heat Flux, MW/m^2	0.483

Table 2. 400 MWt STAR-H2 Reference Operating Conditions Calculated with ANL Natural Circulation Model

Mean Temperature Rise Across Core, C	170
Core Outlet Temperature, C	780
Core Inlet Temperature, C	610
Total Core Coolant Flowrate, Kg/s	16200
Coolant Velocity in SG Tubes, m/s	0.541
Coolant Reynolds Number in SG Tubes	91600