EVALUATION OF TOTAL EFFORT AND RISK OF MEMBRANELESS TUBULAR FUEL CELL CONCEPT

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Abstract. *Traditionally people estimate project risks and duration by comparing predicted actions with similar ones. This methodology is rather difficult to apply in very innovative projects, as several of their Work Breakdown Structure (WBS) actions are quite new to a particular developer, even if this action is a standard procedure in another field or company. This paper proposes the use of an alternative methodology with fuel cell design example, which is inspired in Suh third axiom, Jelinsky-Moranda Model of software reliability (JMSRM). This model considers human error with JMRSR, relates the number of trials with entropy and search residual risk, feasibility with model uncertainty and acceptable and target risks, and the matching of search field and real solution field with statistical tools.*

Keywords*: fuel cell design, risk evaluation, effort evaluation, Axiomatic Design, Fuzzy Front End*

1. INTRODUCTION

Inaccurate time, cost, and effort estimation is the main cause of project failure. If people really do their best, as Oppenheimer in Manhattan project, it's ever possible to find another design if enough resources are available. If before the project begin many solutions to each problem are available, less time will be lost in seeking extra ideas and probability distributions to final specification may be found. The Suh entropy axiom relates the rate of acceptable and design zone with Shannon $\log_2$ entropy and probabilities. It's a mighty tool to get the success chances of each search trial, as well as to find the ratios of search and solution possible field with the entropy of unknown data, here found with time S curves. In parallel, any model may have human errors, reason of JMSRM use, and uncertainties related with standard correlations, grid limits, weak effects neglecting, truncation errors, material variation, parts and processes tolerances. In **F**uzzy **F**ront **E**nd, FFE, people have to settle which project to do or not, and also to elect priorities in the development process. This isn't an easy task. Even a **W**ork **B**reakdown **S**tructure, WBS, may be incomplete, and people may find in a project latter phase that resources are scarce. But if JMSRM is used in checking WBS completeness and quality, the probability of such an event is not only smaller, but seizable. In special we have an oyster to seed in the the hands, a large breathing area membrane free low temperature fuel cell based in μ-flanges, porous and composite walls μ-tubes of many possible materials, that may reach very high power levels and even use CO rich H_2 if its anode Niobium shells are defect free. Its porous wall tubes were made experimentally using μ-fiber **n**on**w**oven fabrics, NW. But even a 5x5x.05 cm anode with 35% in volume of 14 μm external diameter tubes, with a breathing area over support area ratio of 50, has about $5 \cdot 10^8$ tubes, so even a 6 sigma system can't assure a zero anode leakage. By other hand, water vapor outflow opposes the inward diffusion of the fuel mix. New computer CPUs have also so many transistors that a 6σ process doesn't assure error free parts. A 10 kW/dm^3 cell was done in Italy by (Gulino *et al*., 2005), using carbon fiber with an **E**ntangled **C**arbon **N**anotubes cover, ECN, and membrane. This cell has electrodes with a high mechanical strength, a large membrane emf drop, some gas circulation problems and the same sensitivity to H_2 impurities of a normal **P**roton **E**xchange **M**embrane cell, PEM. To eliminate the membrane, the ionomer / polymer impregnated with ion conducting salt in the anode tubes have to be much less gas permeable than normal PEM material, a possible thing as high density PVC without filling is 50-70 time less permeable to H_2, though area is 50 times bigger and thickness 35 times smaller if metal shell adjusts H_2 flux, this gas reacts, and secondary low cost catalyst may be used to capture passing hydrogen in the ECN / metal foam composite support, and also because fillers with high cohesion energy with the polymer and proper size may even reduce such permeability. Bleaching type PEM allows right amount of O_2 to reach H_2 catalysis zone in order to kill CO, and as O_2 is a larger molecule, it is easier to block it. By other hand as explained by polymer gas diffusion models, as for instance free volume model, reducing gas diffusion will also reduce the ionic conductivity. Which one falls faster depends on a large number of factors. The above questions and phenomena are only example. There's a rather many factors and issues regarding the production of the cell of Fig. 1, or its degraded designs of Figs. 2-3, the relative performance and price of all those cells when compared to Gulino one, that will give marked share. As stated by German FFE school (Eggert, 2008) being able to further improve a product family after the 1st product launching is a good thing, but if a company launch the worst degraded version from the ones in Figs. 2-3, how much time it will take to make the 2nd design feasible to marketing? How to convince an investor that the published models of such cells (Bambace *et al.* 20009 a,b) are really good as well as unpublished analysis of: fatigue, cross flow and other items? Is the issue a go non go decision, or it is possible to start research in processes with application in other items, to take latter the more crucial decisions? These and the 40 to 65 relevant FFE questions may be answered easily if reasonable guesses for effort and risks for unusual tasks are available at earlier time. Fig.1 cell operational performance modeling is available in (Bambace *et al.*, 2009 a,b) and its output data reprinted in Fig.4-5. It shall be remembered that a standard 1.0 flex car needs about 600,000 informations to be done, and the Windows code has over 10^6 instructions, so bring to the market a copy of any existing product isn't an easy task.

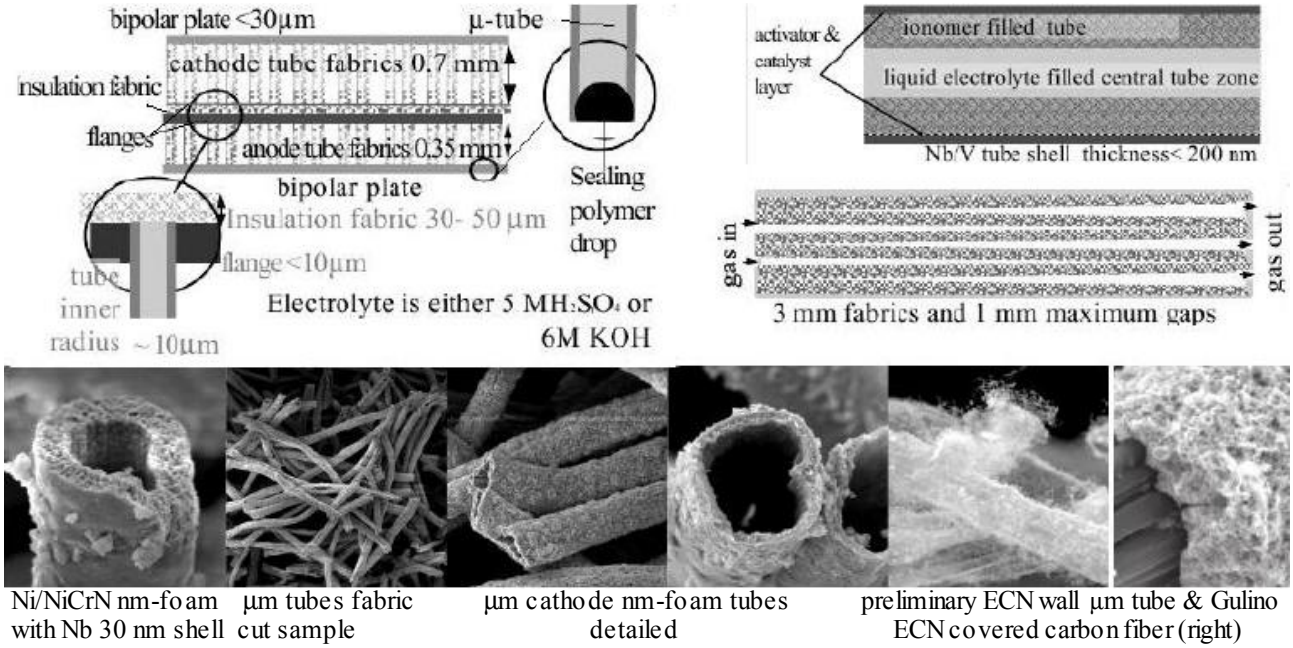

Figure 1: Preferred Fuel Cell Concept, its possible forming elements (nm-foam/ECN)

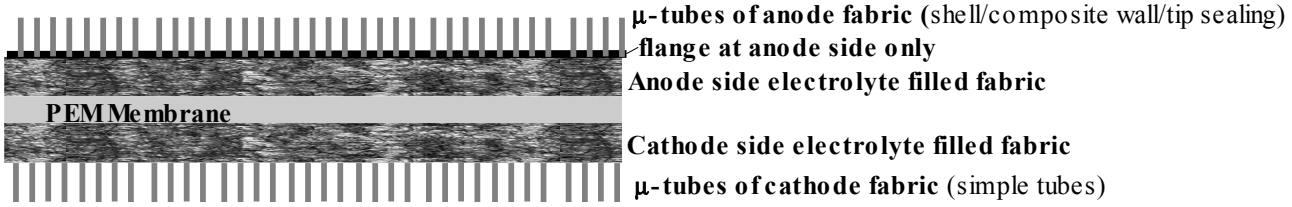

Figure 2: Degraded Configuration with PEM Usage Changes at Cathode/Anode Interfaces Sketch

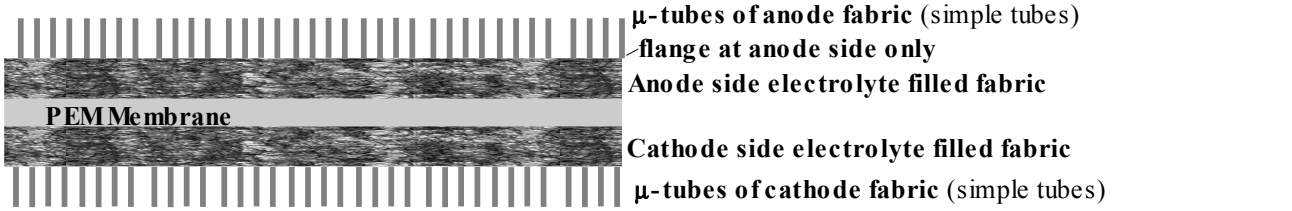

Figure 3: More Degraded Configuration with PEM Usage Changes at Cathode/Anode Interfaces Sketch

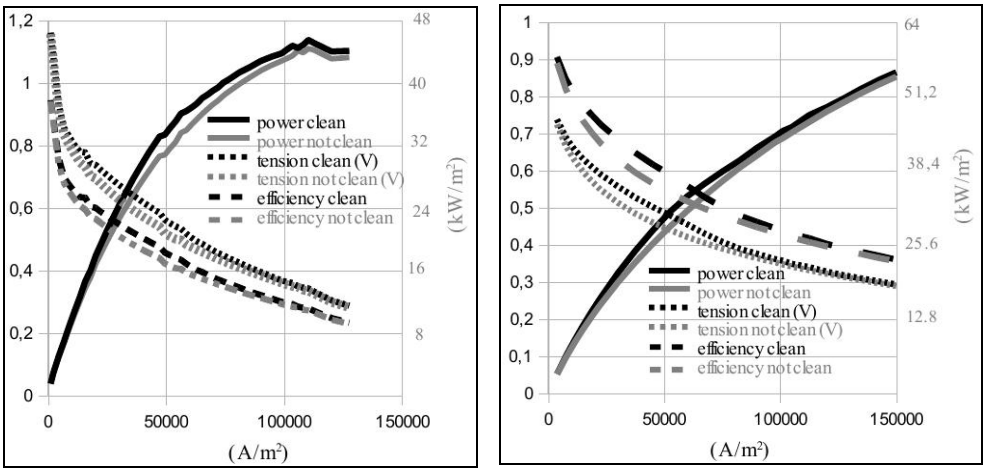

Figure 4: Performance of Pt catalyst Ni/NiCrN/NiCrB nm-foam (right) and NSF acid cells of Fig. 1.

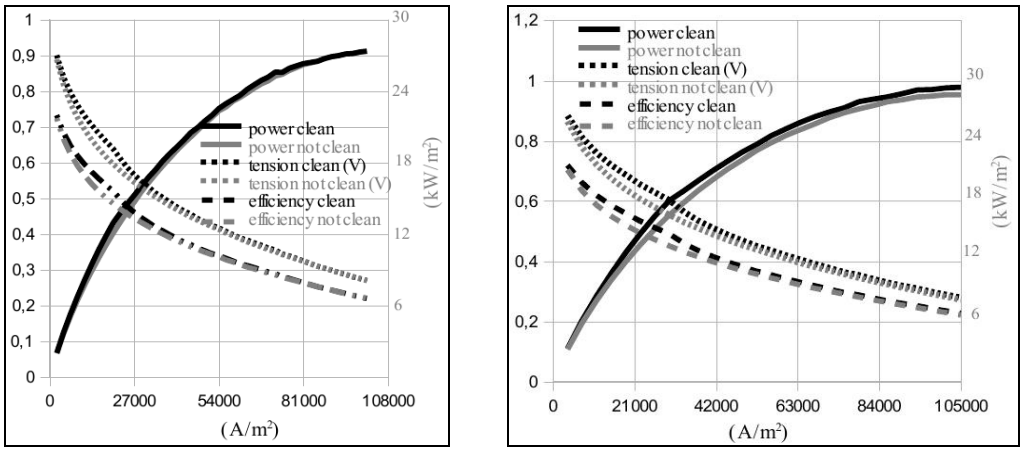

Figure 5: Performance of Pt catalyst Ni/NiCrN/NiCrB nm-foam (right) and NSF alkaline cells of Fig. 1.

2. BASIC METHOD

Maxwell was the 1st to see the information entropy content, with his famous devil, and Shannon (Frey *et al.* ,2000) was the 1st to use entropy as a measure of information content in communication, writing it as:

$$H_o = -\Sigma\, p(x)\, \log_2(p(x)) \tag{1}$$

where p(x) is the probability of the state x. Once any search scheme has a desirable and an undesirable state, the above equation may be rewritten in terms of desired state only as:

$$H = -\Sigma\, p(x)\, \log_2(p(x)) \; -\Sigma\, (1-p(x))\, \log_2(1-p(x)) \tag{2}$$

Considering only one DOF of the above equation, and equating its derivative to zero, one finds that p = 1/2 leads to the peak entropy contribution of a DOF of 1. For complexity evaluation of a situation, there is no desired or undesired state, and the 1st form is more applicable, and peak entropy contribution of a single state is $(e\ \ln 2)^{-1}$. Suh related the success probability with the information content by:

$$2^{-H} = p_s = (\text{common range})/(\text{system range}) \tag{3}$$

where p_s is the success probability of a trial, H the entropy measure of information content. If in machining a part the specified tolerance is smaller than the process capacity, then the system range is the process capacity and the common range the tolerance. If in finding a the cold and water flow balances acceptable to a shower user, the desired flow and temperature limits, common range, is smaller than all the possibilities available, system range. Regarding a documented information, there's a probability p_d that its is correctly documented, and so an entropy $-p_d \log_2(p_d)-(1-p_d)\log_2(1-p_d)$ to each recorded item. If a document is perfect, p_d is 1and its entropy is zero. But this isn't true to all documents, that are sometimes incomplete. This way it is important to evaluate somehow the error probabilities in a documentation, as detailed in a specific subsection. It is interesting to see that for another logarithm in the entropy definition, the relationship between the entropy and the probability changes. Notice that if H is integer, it is the number of bits N used to represent the range rates that is equal the probability. If one uses $\log_{10}$ as base and the rate is integer the number of digits used would be the base 10 entropy. If ones has chose between N≠2 options, the entropy is maximal to p=1/N, and is $\log_2 N$.

2.1. Entropy and The Number of Trials of Common Search Methods

The Shannon entropy H is the number of bits to represent the ratio of problem ranges, its values for p=x or 1-x are equal. Exploring where is the acceptable zone ask for searching it in $K=2^H$ places, with equal probability to each place, the chance to get the right one at 1st trial is just 1/K, and in n trials n/K. Considering a bisection method linear search, dividing the total range in 2 parts, ones has a 50% chance of having the answer in each of it. It's needed to evaluate the middle and a extreme point to know where its, but unorganized people may needless test also the other extreme. If ones sees a key over the table, ones can took it directly, if not, will search all possible places to it. To get a parameter acceptable zone with a given precision in a field, ones have to exam likewise all possible places of this zone in the total field. But before starting a project acceptable fields aren't known, but after bisection solution, it's also possible to write its position as a binary number in the initial field. The middle point is the best 1st trial. For instance, in large electric motors, if ones wants to extrapolate the correlation between the motor power and insulation thickness, this point is the best re-

gression fit, not its limits. A 50% chance of being acceptable may be assigned it, hereafter p_o, as 2 possible states exists. As this success chance is bad many trials shall be made, it's easy to see that in single DOF case, the use $(1-p_o)^{n_t}=(1-p_e)$, hereafter the basic trial equation, leads to a final success probability p_e that obey Eq. (3). After n_t trials the failure probability is 2^{-n_t}, just the acceptable field divided by the total range. For systems with more DOF, but uncoupled, UcS, that's with a diagonal dependence matrix, the same is valid for each DOF with p_o=0.5. Suppose now a wholly coupled 2DOF case. The chance of the solution being in each quadrant is just ¼ and failure chance ¾, a search with much more effort. For an N-DOF wholly coupled problem, WcS, H=N, all terms are ≠ 0 in dependence matrix, it isn't possible to search separately any DOF, but the idea that the search will fail only if all trials fail is still valid, so $p_o=0.5^N$. For triangular dependence matrix, the Suh decoupled systems, DcS, it's possible to fully regulate 1st a DOF and later another, as for instance car seat sloped and horizontal rails, but the field of secondary DOF is forced to be bigger, and its adjust may be repeated to other sets of leftover variables. DcS entropy is intermediate to coupled and uncoupled ones. So, it is possible to link search effort to H. To DcS the procedure in (Frey *et al.*, 2000) is suggested. The more tight is the search risk the bigger efforts, and the smaller its accepted value, the more accurate this procedure, to any system. If a entirely sure mathematical model is available no search is needed and no development effort is needed to find the new product configuration, in fact an optimization in the free DOFs. If an item has no influence the effort is smaller, and also interpolation may help. A general matrix shall be broken in sub-matrices (of UcS, DcS & WcS), each subsystem p_o calculated, to get the p_o value to be used in a basic trial equation of a higher level subsystem. The overall success probability for UcS is the product of individual ones, each specified in the design tree, as difficulties are uneven the chances are not equal. To WcS case, p_o in the same equation is much smaller and shall be directly equated to whole tree branch values. DOF reduction equations inaccuracies degrades a search, so its entropy is added to the search one. If trials are related to a process development, it's needed to find more than a suitable point to evaluate its stability. This evaluation needs extra effort, and the number of good and bad trials obeys Binomial Distributions, but the base probabilities are bigger, as the search doesn't includes the whole field, but the near solution field, the margin is Knowledge Management, KM, issue.

2.2. Entropy from Model Inaccuracy, Documentation and Human Errors

Documentation and human errors are valuated with JMSRM and Mills premise (Pham, 2006), the idea that detection of artificial and real errors of a given kind (sign/comment errors) have equal chance for each error kind no matter if it's a true or an artificial error present in a test review copy, so found and input artificial errors rate is the detection probability, $p_{det\text{-}k}$, of a type-k error, this way $n_{det\text{-}k}$ and $N_{tot\text{-}k}$, respectively found and total numbers of real errors obey:

$$N_{tot\text{-}k} = n_{det\text{-}k}/p_{det\text{-}k} \tag{4}$$

If people knows that all document copies have artificial errors, and if the Enterprise Resource Planning System, as for instance SAP, creates and control the fake documentation, they knew they can't review careless. Predictions of total errors at a review may be related to real values plus errors. The JMSRM assumes that given a constant C, the time, t_i, the i-th error was found, the unknown initial number of errors N_o, the fault detection probability, p_{Fd}, obeys:

$$p_{Fd}= \exp\{-C\ (\ N_o - i + 1)\ \ t_i\} \tag{4}$$

As N_o isn't known, after a given number of inspections of the same person, it's possible to fit by regression a JMSRM with guesses $N_{tot\text{-}k}$ of errors of each type at each inspection. This gives the likely values of all $N_{tot\text{-}k}$ and the chance of successive bad inspections at document release. The KM should record this to previous configured data in order to control the risk of configured documentation errors in final products, decisions, and processes. It's also good to file the "Know Why" to avoid future extra work in past decisions understanding, easing future decisions. Time is relevant, as people need it to inspect, if they're pressed to hurry, fault detection chances drops. All concepts feasibilities shall be verified by models. Another common error is to start an action without planning it entirely. This may be similarly controlled, by taking out of the plan a detail, artificial lack of information, and using the same method. As people forget even what they see in a large list, this isn't a problem to a list of verifications, but more difficult to processes steps, as the lack of a very crucial step is noticed even by people that don't understand well the process. So few people inspect both types of documents, without and with artificial errors before sending files to final inspectors. Only the less detectable artificial errors to the 1st group are in final inspecting files. Fake missing steps may be fuzzily classified in 3 or 5 classes to better the process. Another error is to underestimate a problem difficulties. This is studied in terms of information entropy with S curves. Suppose the number of successful trials of finding a new information over the total number of trials is plotted, it is a mirrored S curve, alike usual ones, but going to zero to large time, it may be written as:

$$S(t)= a[1+m\ \exp(-t/\tau)]\ [1+n\ \exp(-t/\tau)]^{-1} +b \tag{5}$$

As $S(0)=1$, $a(1+m)(1+n)^{-1} + b =1$, and as $S(\infty)=0$, $a+b=0$. Thus a least square fit may be used to find the 3 remaining coefficients. This gives an idea of the ratio of the total data collected and the total data needed. If hypothetically all the

information is collected, there's no risk of a desired solution outside the search zone without human errors. See that if a check isn't in the list, it's an important unused data in the same way the existence of a model in the Internet is. It may lead to eventual failures, as the latter in efforts to rediscover the wheel. Failures ask for redesign, as in the case of Oppenheimer orange crunch instead of cannons use, that may or not be possible. An absent model may lead to the lack of DOFs in the entropy. Assuming that any unused information leads to failure, the Shannon entropy of probable unused information, H_r may be related to the chance, p_{fail} of the project solution be outside the searching zone by $p_{fail} = 1-2^{-H_r}$. S curves may also fit the evolution in time of the number of unknown DOFs, to guess the risk a wrong number of DOFs use, with $S(0)=0$ and $S(\infty)$ not knew, that means a 4DOF least square fit. A relevant error source to S curves and JMS-RM is the wrong time registry of trials. The problem DOFs guesses converges in an oscillating way to the true value as more data is considered, and this may be use as an extra check. If H_r is high to any task it's wise not to start it and to collect more data, once in task detail more uncertainty appears. If a parameter is out of control, for instance the variance of the properties of a bought item of a process out of study, its influence in end properties entropy shall be considered as out of search entropy. Monte Carlo method turns it possible to relate all model correlations uncertainties with output ones. So the probability of that a model acceptable calculated solution to be out of acceptable range may be calculated.

3. FUEL CELL BASE DESIGN DEGREES OF FREEDOM ANALISYS

For the Fig. 2 complete cell, the list of 116 variables related to table values or process average output that are neither related to equations or choices is: exchange currents, secondary catalyst exchange current, anode/cathode catalyst specific area, secondary catalyst specific area, catalysts Taffel slope, anode ionomer/shell/base material expansion coefficients, anode material Young's modulus, H_2 fragility, anode/cathode μ-tube mechanical strength, materials ultimate and yeld strengths, base material corrosion rate, ECN initial & secondary graphitization contact counts, cohesion energies of relevant molecules and its parts, non diffuse EBL capacities per unit of area, effective number of charges, fluid density, dissociated ions diffusion coefficients, dielectric constants, viscosity curve, chemical potential, ECN average radius, shell material $CO/H_2/O_2$ diffusion coefficient/permeabilities, ECN average contact distance, Poisson coefficients, mean radius of anode shell/pores/cracks, anode shell pores diameter variance, anode shell pores diameter third moment, total porosity of the shell, shell tortuosity, anode catalyst average grain distance, variance and skewness, catalyst grain size, variance & skewness, anode catalyst gas permeabilities, shell grain sizes, grain size factor in $CO/H_2/O_2$ diffusion coefficient, ionomer composite mean porous size/variance/moment, material diffusion coefficients in composite/porous walls, ionomer composite closed porous number density/variance/moment, membrane gas diffusion & ionic resistivity data, dissociation constants, anode/cathode μ-tubes mean contact distance, anode and cathode real electrolyte interface areas per unit of geometrical area, anode composite void fraction, anode/cathode/anode shell defects rating, cathode / anode cleaning level. For the simplest possible design, without membrane and auxiliary catalyst to reduce H_2 crossover there's 105 variables of this type. The list of 36 controllable variables of full design, that may be reduced by 2 in simplest case is: cell emf, anode cathode gas void fraction, H_2 supply pressure, O_2 supply pressure, cathode/anode gas flow rate, anode/cathode μ-tubes separator fabric base material void fraction, anode/cathode catalyst load, anode secondary catalyst load, anode/cathode aux distribution parameter, anode/cathode/fabrics/membranes thicknesses, operating temperature, axial load, anode consolidation temperature, electrolyte wetting agent amount, main electrolyte ions supplier concentration, μ-tubes internal and external diameters, filtering metal shell diameter, cathode supplemental feed flow rate, tortuosity control parameter, anode ionomer filler load, gas entrance temperatures. Full design case has also 116 performance variables, that may be reduced by 14 ones in simplest design as follows: cell current, cathode/anode axial electrical resistivity, cathode radial electrical resistivity, anode/cathode axial ionic resistivity, anode/cathode radial ionic resistivity of solid & liquid electrolytes, HER/RRO reference polarization, liquid electrolyte ionic resistivity, secondary catalyst polarization, cathode/anode Electrical Boundary Layer (EBL) currents, $O_2/H_2/CO$ concentrations at anode, O_2 concentration in cathode, cathode/anode effective void fraction, anode/cathode μ-tubes separator fabric effective tortuosity, anode composite area void fraction, anode/cathode gas pressure drops, anode ionomer void free zone free volume, electrodes gas temperature changes, relevant moment of inertia to flexure/buckling, electrodes buckling limit loads, electrodes μ-tubes axial stresses, H_2O vapor out flux in anode shell cracks, effective radial diffusion coefficients in cathode tube walls, reagent concentration drops in anode tube wall & shell or cathode/anode gas flux, diffuse & effective EBL capacities per unit of area, EBL cross potential & pressure, parallel & normal EBL electrical fields, electrolyte positive and negative free charges concentrations, EBL slip boundary speed, pressure & electroosmotic EBL parallel velocities components, EBL normal velocity, parabolic profile velocity parameter, dissociating degree of active electrolyte item, anode/cathode wall material intrinsic ionic tortuosities, anode composite wall gas tortuosities, cathode/anode breathing area, viscosity, delamination stress, shell pores effective Knudsen diffusion, gas force in a fiber, shell axial stress, anode catalyst grain $O_2/H_2/CO$ fluxes, ionomer and base material stresses, deformation energy, electrolyte available volume as the system deforms, extra surface energy due to free fluid surface rearrangement, cathode and anode internal gas leakage, electrodes external gas leakage, membrane electroosmotic water flux, membrane temperature gradient, membrane temperature gradient water driven water flux, membrane ionic resistivity, membrane emf drop, membrane water content, membrane counter ion electroosmotic & thermal gradient driven fluxes, water and ions concentration at both membrane sides, cell efficiency, cathode /anode/membrane/fabric heat generation, bipolar plate temperature, H_2 loop temper-

ature, stress concentration in voids and flares. The variables once separated in the 3 above groups, are placed in a spreadsheet. To the performance variable is possible to make direct pairing to variables and equations, except by one variable, current that shall be paired to ionic current conservation, the list is omitted for simplicity. Control variables set has internal couplings or couplings with performance variables through equations of: imposed H_2 pressure to each current, axial load & acceptable leakage, insulator thickness and minimum electric insulation thickness, air flow rate & operation temperature through heat exchange performance (it may even be regulated), main parameter of tortuosity control & other geometrical data with geometrical formula used twice (anode/cathode). The confidence level for the nonexistence of a forgotten DOF from S curves is 2%, so a 5 sigma 10% extra DOF will be added for safety. If peak power is specified not emf, a peak power equation is added, and DOFs remains. Six of 7 possible physical base quantities, FBQ, are present in the system, that together with these 4 extra restrictions gives 25.1 search DOFs to this the problem has in its most complicated configuration, that is a very small single search trial success probability (1-0.5-25.1). Entrance gas temperatures may be specified as for instance 60oC, to easy cooling design, using Pt as catalyst its amount in anode and cathode specified as in (Bambace et al., 2009), it's possible now to choose minimal thickness and formation temperature, as the minimal electroplating controllable value or a bigger value such that compression stress induced by temperature overcomes 30% the peak stress from other sources, assuring no problems with fragility if cell is heated before starting. If people specifies peak power O_2 and H_2 supply pressures, and μ-tubes inner diameter equal to an easy acquisition μ-fiber in the market, 4 more DOFs are dropped. Cathode supplementary air feed flow rate may be specified by O_2 consumption, filler load specified to minimum H_2 cross flow given a limit radial resistance, and wetting agent concentration set to null, as well as the main electrolyte ion supply component set to standard batteries or to a proven alkaline cell value. Fabric void fraction and 1-2 thickness may be specified also, as its influence is small. Starting with a non-optimal catalyst distribution, auxiliary parameters (2) may be set to 0. So 6.1 searching entropy remain. The normal distribution entropy is $\ln(2e\pi\sigma^2)/2$, with squares of the derivatives of output with input data $F_{o\text{-}i}^2$, it may be rewritten as $\ln[2e\pi\Sigma(F_{o\text{-}i}^2\,\sigma_i^2)]/2$, where the index i means input value, and model inaccuracies effects added to DOFs, resulting in 6.4 value of searching entropy. The chance of finding an acceptable value per trial is 1.18% and failure 98.82%. So 328 trials are needed to assure a 2% failure chance to the search taking the search field is correct. Model failure chances depends on the number of independent model calculations, number of independent revisers with the JMSRM, existence of an automatic time registering or not. Unfortunately with 2 people and a completely new model that asks for a big mathematical model construction effort, there were no independent models, and reviewer are only 2, though the artificial error, AE, source is one of the team members and can't be a reviewer to the errors introduced by him the operation may be made with 2 independent errors sources. Due to time limitation the JMSRM had only 3 extra reviews after the last error detection and only 8 AEs per module in its 8 modules. Resulting model failure probability is 12%. This value may be decreased with more people, more artificial errors, more effort in model correction and alike items. But the composite wall μ-tubes ionomer specification solely is responsible to more than 40% of model uncertainty followed by hydrogen fragility issues, as published data have big uncertainties, that is not wise to start the project without further research in these 2 items. Now consider for instance the no-buckling failure condition, computed values of stack compression loads has a mean value and variance smaller than the bucking load model mean value, this bucking load also has a variance. These variances are due to material variations, and for the axial load due to uncertainty in experimental sealing experiment data used in the correlation. Taking both normally distributed it's possible to each bucking load value to get a probability that the compression load is bigger, integrating this probability multiplied by the probability of each bucking load, ones has the bucking failure probability, with no gas flow. Dependence matrices must be written to control alike procedures. If all variables are full coupled the Monte Carlo method may be used to get the failure chances due to model uncertainties. For the current case the failure chance is 1.3% for a minimum peak power of 0.3 kW/dm^3, a projection for automotive fuel cell 10 years horizon requirements, or 7.3% if the cell has to operate over Gulino fuel cell estimated power. A mirror S curve showed that the error chance of not finding an extra information is 4.37% (70 trials search with a 68.3 chi-square parameter). It's possible now to get the chance of a solution being out of search field as 1-.880x.927x.956 = 0.220 against Gulino cell or 0.170 for the other case. For instance, using a membrane but not neither a shell nor a polymer in anode, the new system has a smaller error, but will still have some common sources of errors (ex.: buckling). So studies with project parallel options trees shall consider failure of no mutually exclusive events. For different materials (ECN/metal nm-foams, NiCrN nm-foams) material relative data are independent, but not the models used to find design limits. As there are many material and designs alternatives the chance of no valid design drops, even with the available data. But there's also the need to build any solution, that requires process development to a good level. The independence of different processes in development tree is assured if they don't use the same fault equipment. But as many processes enters in the manufacturing, the difficulty rises, but the use of alternative designs and materials mitigates the fabrication risk growth. Several processes and materials from other fields helps. For instance Curvature Enhanced Accelerator Coverage processes, CEAC, related to under-potential catalyzed electroplating is useful in microelectronics, tensoactive mediated electroplating is used in Li-Batteries. The number of search DOFs to all process options related to the considered cell alternatives, as well as the numbers of trials to find the 1st success point to preliminary specifications, the predicted success probabilities, and number of trials are in Tab. 1. As at the beginning of the project we did not have this method in mind, some early processes have the number of tries not registered.

Table 1. Processes development, effort & results data related (**d**eveloped, **u**ndeveloped, low **p**erformance, bad **v**ariance)

ID	Process	# of variables	FBQ	DOFs	$n_t(p_e=0.98)$	# trials did	Status
1	Crude μ-fiber activation with commercial baths	3	5	2	13+6	4	d
2	Vapor degrease cleaning (with not standard solvents)	7	4	2	13+6	3ǂ4ǂ5ǂ8ǂ9	d
3	Solvent ultrasound top quality cleaning (Eq. Hansen)?level	7	4	2(1)	13.6 (5.64)	5/3/2/4	d
4	Direct NW activation {rayon/ polyacrylonitrile (PAN)}	5	4	1	5+64	3	d
5	ID 4 tensoactive intermediated pulsed electroplating	11	6	5	123+22	12	v
6	ID 5 mold removal (b_{urn}, hot pure H_2SO_4, chlorides, hot solvent)	14ǂ16ǂ16ǂ14	4ǂ5	4ǂ**5**	60ǂ**123**	3ǂ6ǂ**17**ǂ**6**	d,p
7	ID 1 tensoactive intermediated pulsed electroplating	10	6	4	60	6	d
8	adsorption of protective polymer in ID 7 item	7	4	3	29	12	d
9	ID 8 after ID 4 joint protective polymer & mold removal	9	4	3	29	12	d
10	Cr radiolytic nm-grains deposition on ID 5/7 nm-foams	13	6	5	123	?	p
11	Test plane plate with Cr placing & grains hot diffusion	7	4	3	13	?	
12	1200 ºC ID 10 pure N_2- Nitretation (Los Alamos receipt)	6	4	2	13	2	
13	Hot Cr diffusion in ID 10	7	4	3	13	?	d
14	ID 1 μ-fibers Hydroentangling (J&J,DuPont,Freudenberg)	10	3	7	498.8	n.a.	n.a
15	ID 13 1200ºC nitride	6	4	2	13	?	d
16	ID 10 formation of NiB inert layer	6	4	2	13	?	p
17	C_2H_6 ECN on Al_2O_3 plates (impregnate+std[5]+clean)	(4+5)+5	4ǂ4	5+1	123+6	0	
18	C_2H_6 ECN on Al_2O_3 NW (impregnate+std+clean+dissolve)	(4+5)+5+5	4ǂ4ǂ4	5+1+1	123+6+6	0	
19	C_2H_6 ECN production on semi burned PAN NW	(4+5)+6+5	4ǂ4ǂ4	5+2+1	123+13+6	3	p
20	CH_4 ECN production on Al_2O_3 NW	(4+5)+5+5	4ǂ4ǂ4	5+1+1	123+6+6	0	
21	CH_4 ECN production on quartz NW (? quartz μ-fiber cost)	5+6	4ǂ4	5+1	123/6	0	
22	CH_4 ECN production on semi burned PAN NW	(4+5)+6+5	4ǂ4ǂ4	5+2+1	123+13+6	0	
23	ethylene glycol & polypyrrolidone Ag nanotubes on NW	9 (receipt)	4	5⇒2	123⇒13	3	p
24	Idem to 23 on single nm-fiber	9 (receipt)	4	5⇒2	123⇒13	3	p
25	ID 23/24 mold removal	14	4	4	60	0	
26	Secondary dilute polymer graphitization on IDs 17-22	13	5	1+2+5	6+13+123	0	
27	Similar to 8&9 to ID 24	7+9	4	3+3	29+29	**0**	
28	Direct making of ECN in crude fiber with best of 17-22	9+6+4	3/2	6+4+2	123+6+6	0	
29	Similar to 8&9 to ID 28	7+9	4	3+3	29+29	**0**	
30	4 steps anode μ-flange barrier to H_2 making	9+3+5	4ǂ2ǂ2	5+1+3	123+6+29	16	p
31	NW sealing with tip drop of diluted polymer & remelting	10+7	4ǂ4	6+3	248+123	22	p
32	NW plasma activation for good wetting (std)	6	3	3	6	?	d
33	Any electrode radiolytic pure Pt catalyst deposition (IPEN)	13	6	5	123	?	d
34	Any electrode radiolytic Ru-Pt catalyst deposition (IPEN)	14	6	6	248	?	d
35	ID 17-22 mold removal	14	4	4	60	0	
36	ID 5,8,25,35 wall fill with ionomer precise gelling+remelting	8	3	4	60	10(Nafion)	p^{text}
37	One ID 36 Nb ionic liquid 25-85ºC electroplating (3≠IL ∃)	13 (receipt)	6	5	123	2/0/0	pǀuǀu
38	Preferential directions in NW marking to easy mounting	8	3	2	13	(receipt)	d
39	Idem to 30 to cathode that has free walls	9+3+5	4ǂ2ǂ2	5+1+3	123+6+29	0	
40	Radiolytic welding of ID 37 anode NW layers	6+14+7	3ǂ6ǂ4	3+7+3	29+248+29	0	
41	Radiolytic welding of any ID cathode NW layers (NiCr)	6+14+7	3ǂ6ǂ4	3+7+3	29+248+29	0	text
42	Cathode NW layers liner-polymeric bond (solvent selectivity)	6+8	3ǂ4	3+4	29+60	0	text
43	Anode NW layers polymeric bond (solvent selectivity)	6+9	3ǂ4	3+3	29+29	0	
44	Anode NW layers welding with ID 37 alike process	14	6	6	248	0	
45	ID 37 directly on pressed NW layers	14	6	6	248	0	
46	Cathode NW layers welding with ID 7 alike process	11	6	5	123	0	
47	2nd graphitization bonding of cathode ECN NW layers	14	5	1+2+6	6+13+248	0	
48	Bipolar plate with PVC impregnated Tungsten Carbide	8+6	3ǂ4	4+2	60+13	0	
49	Los Alamos Patented Ni bipolar plate with NiCrN layer	ID11+ID12			13+13		d
50	Production of bipolar plate with $Ni_a\ Cr_{(1-a)}$ B layer &test	8+6	4ǂ4	4+2	60+13	0	
51	Polymeric case making			3			
52	CEAC use to make ID 4/6 items stronger	6+10	4ǂ5	2+5	13+123	0	
53	Cleaning to enhance electrocapillary transport	n x 7	4	2	n x 13	0	
54	Polymeric foam making on electrode assembly to reinforce it	9	4	5	123	0	
55	System integration			3	29		
56	Silver radiolytic 3-4 nm grains	13	6	5	123		
57	nickel radiolytic 3-4 nm grains	13	6	5	123		
58	LiNiO Bacon Spinel	9	5	4	60		
59	Secondary organometallic	10	6	5	123		
60	Manganese Spinnel for H_2 (patented Korea)	9	5	4	60		

Better review and control will reduce human errors. With more careful model reviews, involving more people, it's possible to eventually better the success chances, if model confidences increases, and the predict field is right. It shall

be stated that the process of filling a wall with a ionomer was did to the Ni wall only, not the NiCrN, and with standard Nafion, not the end polymer, also without filler. The temperature and ionomer mechanical parameters interferes in the outer vapor flow in shells cracks / pores and in sensitivity to CO, and related probability evaluation shall be done again after the final ionomer specification. As we don't have entangling equipment, related tasks were not done. For instance adsorbing a polymer in a porous wall involves that the pore volume plus polymer one nearly match the wall free volume, and that wall surface energy is above the polymer and polymer/solvent solution. Its involves good cleaning, so cleaning time in ultrasound equipment, solvent used, contamination level, matching of Hansen solubility parameters of contaminant & solvent, temperature and average contaminant molecular weight, acoustic pressure used. The cleaning DOFs taking out 4 FBQ and a equation is used, so to each contaminant the optimal cleaning involves 2 DOFs, and n_t of 13.6, but as ultrasound level is anyway laboratory equipment, one degree is out. The parts where contaminated with 4 different materials: oil, rosin, fat, exposition to uncontrolled environment, used solvents were respectively hexane, isopropanol, methyl-ethyl-Ketone, and trichloroethane. Trials used were 5, 3, 2, 4. But a high ultrasound level could break items, and a to low not clean at all. To absorbing the polymer and getting there are 7 variables and 4 FBQ, and 3 DOFs remained, and 12 trials were used to adjust the process. Mold removal is a dynamic process, in burning useful to metal, this material also degrades, in dissolving, the dwell may induce stresses, eventually breaking internal elements. If the solvent first dwell the entire material content to then starting dissolving at surface, stresses are maximum, if it dissolve surface material before dwell everything, the stress decreases, if it dissolves directly surface material there's no stress, and the hotter it is the bigger such a chance, either using Hansen or Flory models. All process variable list have to include relevant output variables to the desired item affected by the process. That's why some similar processes have different DOFs in table 1. Room temperature Nb electroplating may be done with imidazolium chloride, amides and organic sulfur compounds, being the 1st patented by USAF, (Cheek *et al.*, 1999), and easily reproduced with the patent, as we did, but not commercially usable. This procedure as well as use microscopic optical fiber to make a ECN shell can however be used to built test model to clarify the desired fuel cell behavior. Radiolytic deposition processes to nm-grains were developed in IPEN as a thesis work, and the process further developed and modeled to catalyst deposition uses, resulting in a Brazilian patent (Silva *et al.*, 2005). In ID 41, the union is in the dry H_2 feed zone, were corrosion is not severe, and a low cost material may be applied, in the ID 42, the material may be in and alkaline cell, and in this case done with nickel before catalyst application, or be done with Ni-Cr salt mix, the table case study, before the nitretation and catalyst placing. Filling a material with a polymer with its solution is not a big problem if polymer and solvent surface energy are both smaller than any surface point, as the solvent dries, more material goes in the porous structure, till a near gelling mix forms, this way the tube and structure will push the mix, and then the wall will get mix from tube free center. The problem is voids, and bad cleaning, and final accommodation, the slower the solvent evaporation in end phase the better the results, and remelting may correct small voids and imperfections. This technique was done out of the fuel cell project with metal foams and acrylic. The 14 already developed processes have no related risk.

Possible output fuel cell may be classified in terms of 11 main attributes, besides oder secondary ones. The cell may be an acid electrolyte one, A, an alkaline electrolyte one, K, or an aprotic ionic liquid one, I. It may have a gas tight anode, T, a partially tight anode and relative thin membrane, P, or have a membrane between 2 fabrics with electrolyte without composite wall, W. It will have oriented μm-tube fabrics for types T and P, for type W it may have oriented tubes also, no letters, or not oriented tubes, C. The cell may also have only Pt catalyst, c, Pt-Ru, b, Ni-Ag alkaline pair, s, Ni-Bacon Spinel alkaline pair, i, and eventually auxiliary low cost organometallic catalyst to help trap H_2, o. To be an acid type the cell has to have electrodes of materials that do not suffer from corrosion in such media as: $Ni_xCr_{(1-x)}N$, $Ni_xCr_{(1-x)}B$, Ni_xB, to $0.35<x<0.7$, or ECN. To be alkaline the cell may have any electrode material, but as expensive ones are not recommended to low cost smaller performance cells, only μm-tubes of porous walls of silver nanotubes or nickel nm-foam will be considered. To be type I, any material may be used, as aprotic ionic liquids are low corrosion ones, they have smaller ionic conductivity than strong alkali or acid electrolytes, but they have very high gas permeabilities, orders of magnitude above normal liquids. Alkaline cells may have Pt or Pt-Ru catalysts to special applications as Bacon cells adapted to Gemini and Apollo missions, but preferably they will have either type s or i catalysts. Type b and c catalysts are 100% sure processes. Table 2 shows the probability of each attribute, and to A type only existence of an electrode is considered. Notice that an alkaline cell has problems with good enough alkaline membranes, as the best published ionic conductivity is 5 mOhm·cm, (Mitchell, 1963). They have as advantage that electroosmotic flux is contrary the H_2 flux, that allows then to be thiner. As tehere are 6 processes the chance of an ECN based material wall is 99,66%. The chances of a nickel wall is 97.83%. With this wall to get a non ECN tube without filling it is still necessary to make either a direct bore compound, or to make a Ni and CR compound that then may be transformed in nitride or boride. If no electrode is produced, 0.0084% or an silver or pure nickel electrode is done but there's no acceptable membrane, there is no cell, 20.85% of chance, so chances of no cell is 1.75E-0.5, regarding no electrodes. So the main risk is in the no parallel process to integration, case making and alike items made process related failure chances to be 27.91%. So to make parallel development of such items is important to better success chances related to processes. Notice that there's also a design error risk, with 17% of chances of do not exceed Gulino fuel cell performance or a 4.37% chance of not exceeding the projection of future PEMs performance. To make table 2, the S curves of both types were used to evaluate out of search problems. In principle variables with big effect in mean value and low effect in variance and shall be preferably used to set operating point, in order to reduce output variance and item rejections. So it is im-

portant to register data to evaluate the effects in mean and variance of all variables in process development. The existence of a good item does not assures a controllable process, and we are trying to develop a tool to evaluate the controllability of the process during its development. Many processes of general usage have models in the literature, to answer this question. If the influence of variables in mean of variance of process are monitored, it is possible to exclude the use of a process without extra variables, before a high number of trials. In this case as the number of trials rise to much with increase in DOFs, and as an item not directly controlled may be controlled with an extra field effect and an extra material sensible to that field, and is better to use an already existent field, one or 2 propositionally extra DOFs probably suffice to correct the process, and the process failure probability may be approximated with in general large safety factors by the probability of success of a process with 2 more DOFs for the given number of DOFs of current process. The existence of a successful item or good results of the process in another field is a good indicator of its usefulness. 10 years ago, nobody would say that was possible to make by electroplating a completely void free nanometer via, turned possible by CEAC. It is also showed a Task tree for production of non ECN walls without catalyst activation in Fig. 6. It shall be noticed that an a analysis with an alike process to any project, helps to find the weaknesses of the develping plans of any items. Even if there's methods to evaluate the tasks chances based in previous experience, comparing this method and a standard one helps at least to find human errors. If the management develops correlations between this method and other internal methods of any institutions, as for instance analogy with previous work, it is possible to a manager without experience in an issue to detect misuse of any internal method, this is important as to use standard methods, the operator shall know very well the analyzed item, and no people will know well everything.

Table 2: Success Probabilities Getting a Characteristic

Attribute	(P_s)	Attribute	(P_s)	Attribute	(P_s)	Attribute	(P_s)	Attribute	(P_s)	Attribute	(P_s)
A	0.8569	I	0.9819	P	0.5462	c	1.000	b	1.000	i	0.7314
K	0.8735	T	0.3543	W(A)	0.9888	C(A)	1	s	0.7334	o	0.8540
				W(else)	0.7911	C(else)	0.8				

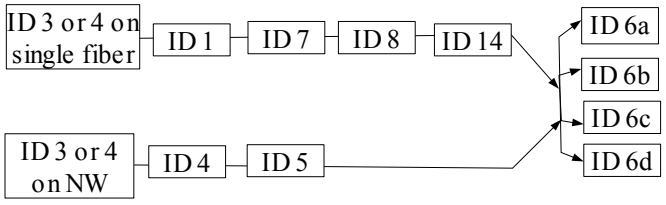

Figure 6. Tasks Tree for Making a non ECN Wall Without Catalyst Activation

4. CONCLUSIONS

The proposed effort and reliability of new projects model is promising, and is statistically consistent with our few past process and project development data, but it shall be further tested. To do past design data of other projects related to consumed effort and reliability shall be used. With this data people will become more confident in this model, or even better it. Our main hope, is that once a effective prediction model to entirely new endeavor effort becomes available and accepted, financing innovative projects becomes easier. It also shall be emphasized that the relative ranking of two possible projects is easier than find absolute effort and risk data, as mis-organization of a project team may increase the effort, as Einstein once said that is not an intelligent position to think that the results will be different when the same things are done. Somehow lack of organization leads to unnoticed neglecting of Einstein advice, leading to more effort, and in parallel processes sensitivity modeling to parameters variations, and good enough initial specifications may be lacking at very beginning, as well as Knowledge Management data regarding to process refining. But as all these problems have similar effect in compared options, such procedure is more reliable. The procedure will easy the decision of either developing with Reverse Engineering a conventional concept with a large number of DOFs or develop a promising brand new idea. Particularly, the proposed cell design used in the procedure testing is by our point of view a promising design, though it is not the single non-planar geometry in development. It has less mechanical strength and electrical conductance than the Italian design here cited, but more breathing area, better gas flow concept, better ionic conductance and a higher theoretical power output, as ionic resistance is more relevant than electrical one. If membrane is eliminated, the cell will be able to work with less pure and even high CO content H_2. The possibility of developing more than a single configuration with the same processes and the existence of more than one process to make each item, reduces strongly the risks. This policy makes the final specs of the project and its financial returns random variables,

but turns it possible to evaluate their distributions. Once this or another evaluation process become reliable, we expect to turns the test example fuel cell project a well structured one, with enough resources, people and funding.

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