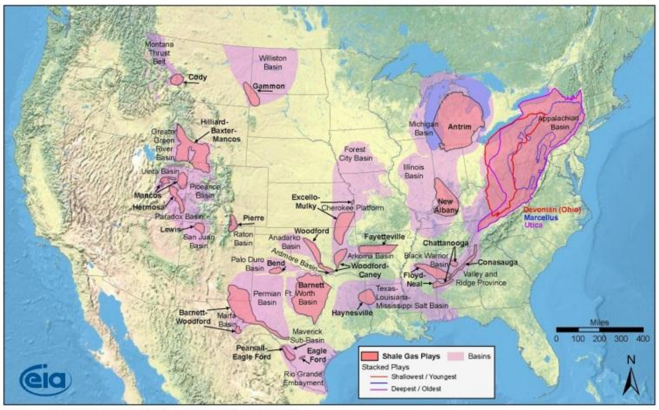
KAPPA Consortium
On Unconventional Resources
Draft project document – 7th February 2011

A - Introduction

Unconventional resources that include shale gas, CBM, shale oil and hydrates, are a hot topic today, with an explosion of publications and initiatives across our industry. Easy oil and gas reserves are now, in the main, owned by National Oil Companies (NOC's). Unconventional resources and deepwater are therefore the two main options that remain open to international operators. Even NOC's are taking an active interest in unconventional resources for domestic consumption.

Shale Gas Plays, Lower 48 States



Source: Energy Information Administration based on data from various published studies
Updated: May 28, 2009

At KAPPA we focus on the use of dynamic data. For shale gas, dynamic data is a critical piece of the puzzle, as this impacts reserve booking and production forecasting. In the last three years KAPPA has developed dedicated analysis tools and models based on the hypotheses accepted by the industry.

The results are presented in a WEB publication: '*The Analysis of Dynamic Data in Shale Gas Reservoirs (Parts 1 and 2)*'. http://www.kappaeng.com/downloads/shale_gas

At the cornerstone of the KAPPA work is a numerical model, which includes most of the common hypotheses. Specialized plots and analytical models complement this model.

The solutions presented by some of the other protagonists in the industry have been somewhat different. Some technical groups are indeed offering numerical alternatives, but in most cases the focus is placed on specialized plots and the desorption mechanism. The main tool is a square root plot to assess the linear flow orthogonal to the fractures. A material balance plot is also used when apparent Pseudo-Steady State (PSS) is reached in the Stimulated Reservoir Volume (SRV).

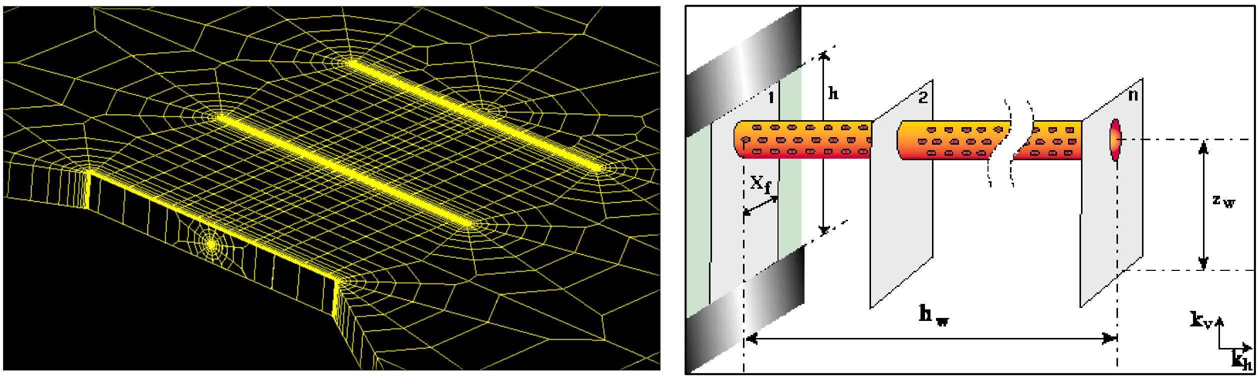
These tools are useful to arrive at a first approximation of the parameters. What is more questionable is to use these results, straight lines and simple analytical models, to run long term production forecasts. It is not valid to simply extrapolate transients, and approximating a fractured horizontal well by a single longitudinal super-fracture is plain wrong. Such methods do not take into account the complex geometry of the flow and the nonlinearity of the diffusion. The latter, to us, is the main issue in this kind of production environment.

In this document and annex we describe the current approach by KAPPA. We list, without going into detail at this stage, what needs to be done in order to reach a minimum objective: to be able to simulate events before they occur, and not look back with regret at deviations and try to justify them after the fact.

We then present the rationale for a consortium on shale gas which will then be extended to other unconventional resources such as CBM, Shale Oil and Hydrates.

B – Shale Gas. What is the problem?

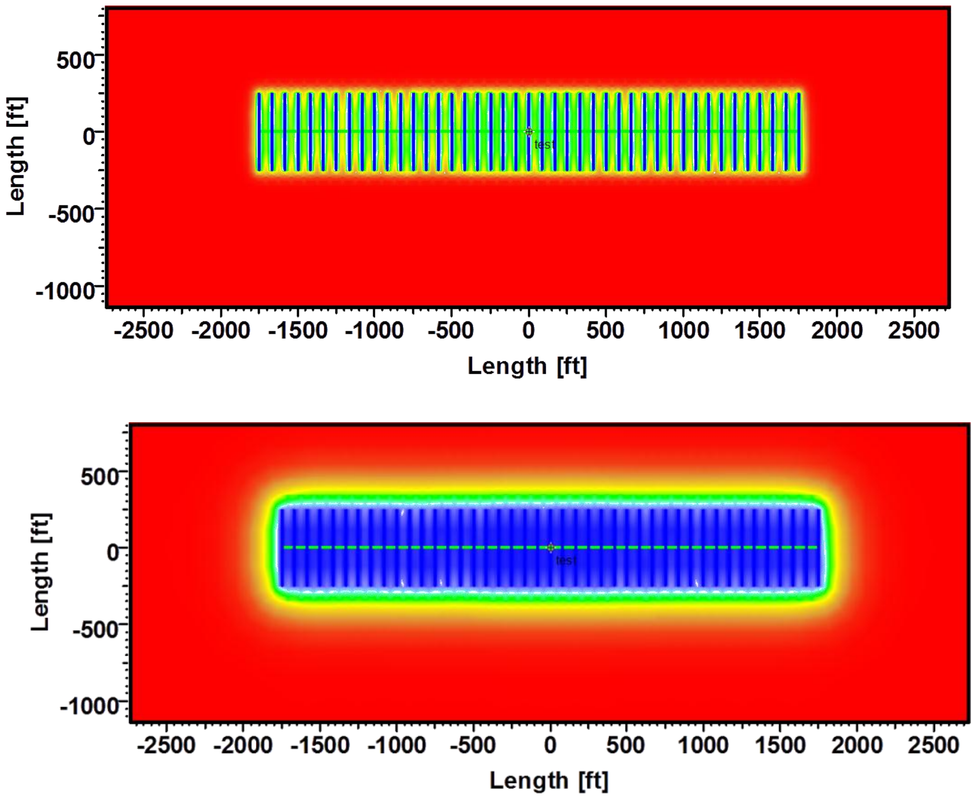
Because we are in ultra-tight formations we need a large interface area between the reservoir and the well. We do this by massively fracing horizontal wells. Modeling this can be done numerically or analytically, and transient behaviors can be approximated by straight lines.



Numerical (left) and analytical (right) fractured horizontal well models

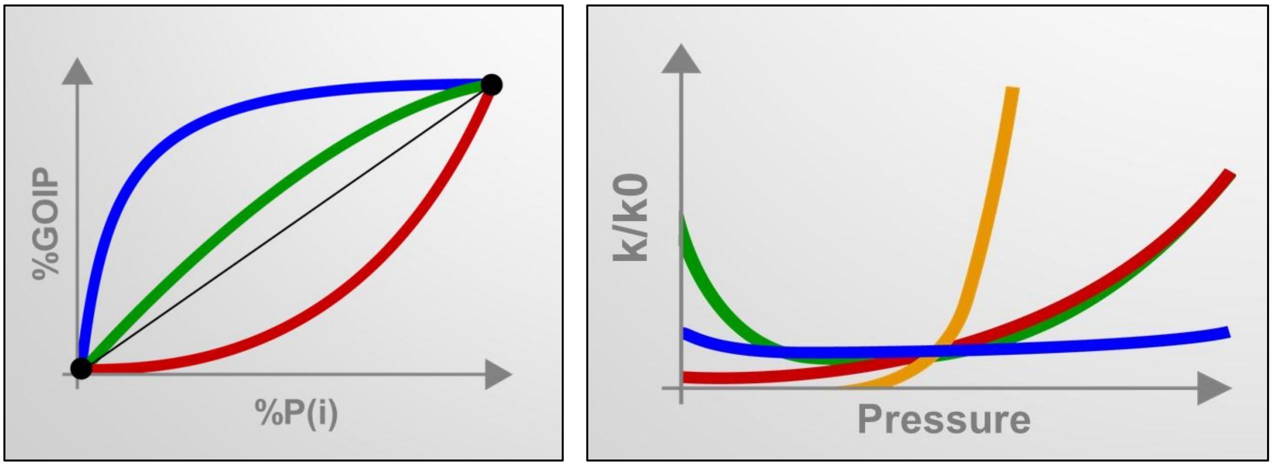
'All' we want is to quantify the main mechanisms in order to forecast future production and correctly book reserves. But doing this properly does not come easily:

- The very low permeability induces significant pressure gradients throughout the formation. Gas properties radically change when moving away from the fractures and simple analytical models and specialized methods do not capture this. Many focus on desorption as the main modeling challenge. However, we believe nonlinearity is the real issue.



Pressure gradient after 8 months (top) and 10 years (bottom) of production

- Diffusion is not straightforward, and many mechanisms may affect the gas flow: Stress dependence, Klinkenberg effect, Bingham diffusion and, yes, desorption.

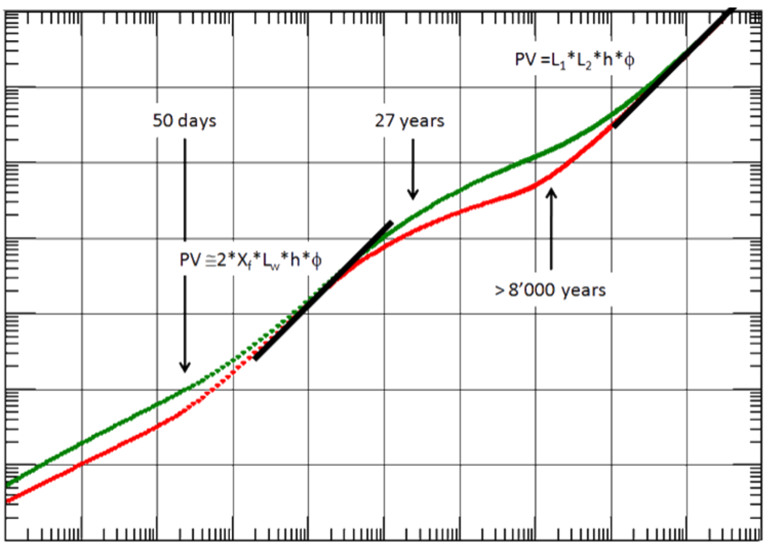


Desorption (left) and stress dependence (right)

- There is also the question of the fractured network. The hydraulic fractures open some cleats, but there are others. Taking into account a secondary network of fractures can radically change the estimate of the production, and whether or not production will go beyond the SRV during the economic life of the well. Even on such fundamental issues there is no unanimous agreement.

- In these intensely low permeability formations 'your reservoir is your well' as Christine Economides puts it so succinctly, or as the old tight gas hands used to say: 'you get what you frac'. The part of the reservoir that is the most likely to produce anything to a given fractured horizontal well is a slightly inflated version of the volume trapped between the fractures at the extremity, called the Stimulated Reservoir Volume (SRV).

For the same reason, 'your test is your production'. In a standard formation we use a few hours or days of shut-in to identify a transient model. The time to Pseudo-Steady State (PSS) may be longer, but still the order of magnitude will be the same. The result of the analysis will then be used to forecast the production. In shale gas we are constantly in transient conditions. Even when we see PSS in the SRV it is, strictly speaking, only a long duration transient. Depending on fracture density the PSS may indeed never be seen.



Typical transient response where PSS is seen in the SRV

C - What KAPPA has done so far

In Ecrin v4.12 KAPPA released or updated two specialized plots (square root and material balance), a set of analytical models and a numerical model that are aimed at addressing all or some of the following behaviors:

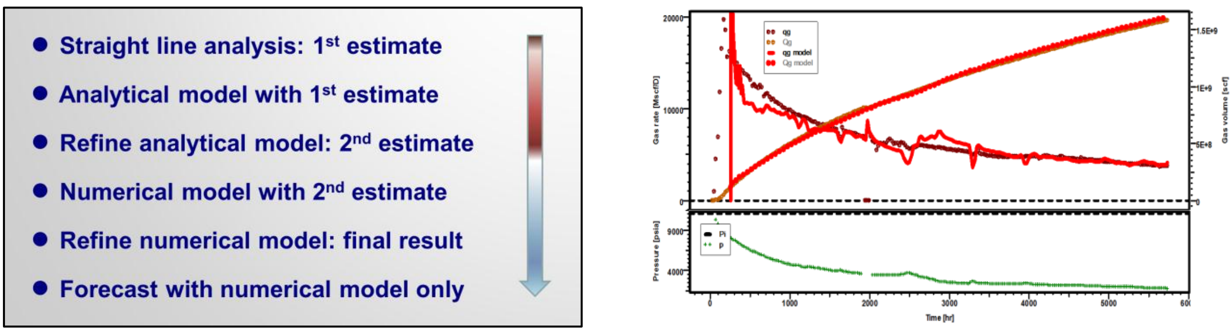
- 'early' time global linear flow orthogonal to the fractures
- interference between the different fractures
- diffusion of real gas in a tight formation accounting for the increase of the gas compressibility when the pressure is depleted close to the fractures
- pseudo-steady state in the SRV, whenever it occurs
- desorption of the gas from the shale
- pressure dependence of the permeability

A simple matrix illustrates which model/option can handle what. The white circles correspond to behaviors that are partially, but not rigorously, taken into account using pseudopressures or other correcting functions aimed at partially linearizing the diffusion equation.

	Square Root	Material Balance	Analytical	Numerical
Early time linear flow	●	-	●	●
Fracture interference	-	-	●	●
Real gas diffusion	○	○	○	●
PSS in SRV	-	●	●	●
Desorption	○	○	○	●
Stress dependence	○	○	○	●

It is no surprise that the Numerical model is the only option that has the capacity to rigorously address the whole spectrum. But how rigorous do we need to be? The different potential errors in the other methods are described in Part 1 and quantified in Part 2 of our WEB document.

Both specialized plots and analytical models have their roles and there are many different parameters in the 'final' numerical model. The proposed workflow is to increase progressively the complexity of the analysis. This starts with straight lines (linear flow) and is refined with analytical models accounting for flow geometry and fracture interference. Finally it uses the numerical model to account for everything we know.

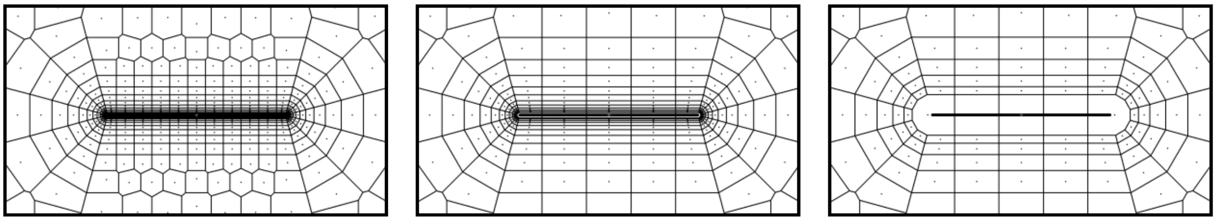


Typical workflow (left) and typical history match (right)

Today we believe the methodology and models available in our software are the best (or the least bad) available to tackle this problem.

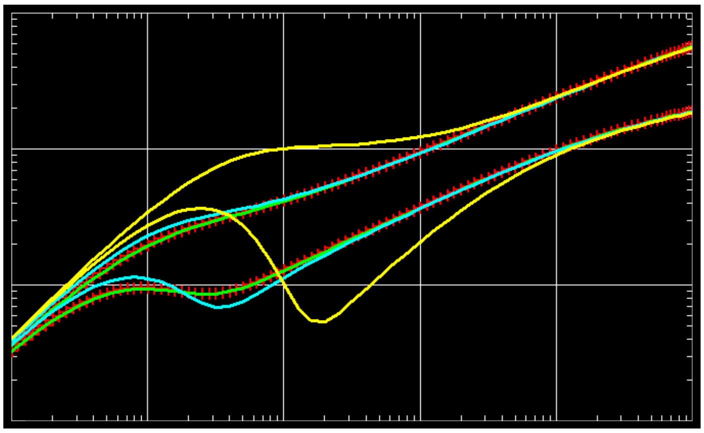
D – How we got to where we are

We are here because we had a fortuitous jumpstart. In 2000 we worked on the problem without even knowing it. We designed a numerical model that would work on well test data, using an unstructured grid in order to generate pressure responses on a logarithmic time scale. The grid was calibrated and consistent with analytical models whenever such a model was available. The automatic gridding was initially tuned for Pressure Transient Analysis in Saphir. Later we increased our range of applications and adjusted the numerical model by using coarser grids for Production Analysis (Topaze) and History Matching (Rubis).



X-Y cross-section of the grid around a horizontal well in Saphir / Topaze / Rubis

In the background, the well-to-cells connection was adjusted on the coarser grids by making a real-time comparative simulation between such coarse grid and the refined well test grid. At early time the coarse grid response would be inaccurate, however the well index of the coarse grid was adjusted to match the late-time response of the well test grid.



Coarse grid calibration

Initially we assigned a grid setting for each software module (Saphir, Topaze and Rubis) irrespective of the permeability of the reservoir. The assumption was that, for a normal range of permeability, the grid in the relevant module would suffice. The geometry of the cells would, or would not, determine which behavior would be detected. Everything was fine until we started working on shale gas.

For a micro-Darcy or nano-Darcy formation, even the refined grid developed for pressure transient analysis was insufficient to match the long term shale gas production decline. We had to 'hyper-refine' our grids when dealing with shale gas, even for relatively large time steps. This work, to be released with Ecrin v4.20, is complete and was used in the WEB document.

In v4.20, due for release in Q3-2011, the scaling of the automatic grid will be adapted dynamically to the permeability around the well and the smallest required time step. The size of the smallest cell close to the well is defined by an equation similar to the one for the radius of investigation of a well test. This adaptive gridding is now able to cover automatically any range of permeability, even in the extreme. Adding nonlinearity is then relatively easy.

E – Why a consortium?

In the last 20 years KAPPA has developed software using its own resources and funding. We consider that developing new features is our problem and should be self-financed. We just sell you the resulting products. Sometimes, our clients request developments that they fully or partially finance in exchange for limited time exclusivity. To date we have never taken the initiative for such projects.

In the past we have possessed all the expertise and had sufficient access to real data to initiate and bring our own developments to market. But this is different. Unconventional gas is new territory. The work we have done so far has been based on reviewing the literature, theoretical assessments, a bit of common sense and a lot of hard work. We had access to just enough data to validate our models. We could continue in this vein, keep on reading the literature, implement what our users ask for and deliver products. However we believe this is no longer sufficient:

- The stakes are too high and the technical cycles are too long. The industry is investing billions, booking reserves and pinning their future on this now. A 5-year lag between a relevant idea and its viable commercial availability in a PTA / PA / History Matching software tool is too long when the correct analysis and subsequent forecast and reserve booking could have such a massive impact on the cashflow and balance sheet.

- KAPPA cannot do this alone. Decisions to develop, or not, a model or process needs to come from a collective of talented engineers exposed to real-world problems and not just sieved from the literature by a software vendor.

- We need access to much more data to validate the different concepts and our implementations.

- To put it mildly, we are not convinced by some of the things the industry is doing and publishing. What we seek is the technical truth. To do this we need input from the engineers who have been involved in this for years. We need to use external resources to complement our know-how.

- If we collate all this, the work involved in the gathering of information, technical dissection and implementation in the software is beyond our usual self-financing model. We then have the choice of partnering or seeking outside finance. Both of these options are undesirable as they conflict with our independent desire to provide solutions to our clients as a whole and introduce a profit motive to the project that could override our overall objectives; the technical truth and improving our software.

To summarize; we need more funds, more resources, more interaction with end users and much more data. A consortium seems to be the right answer for such a combination of needs for KAPPA and our clients.

F – Tentative content and thought starters

The content of the consortium will be reviewed on a quarterly basis. The list below is purely indicative, a tentative version 1 of the consortium to-do-list.

For each item, the work would involve not only writing software but also research, bibliography, software implementation, tests, data-hunting and validation on real cases.

Analysis tools
Although it is not the main technical interest of the consortium, we have seen that specialized tools are useful to provide a first estimate of parameters for the analytical and numerical models. Hence, any specialized plot or new straight line deemed to be relevant will be added to the analysis toolkit in Saphir NL and Topaze NL.

Individual fracture properties
Analytical and numerical models currently available have a uniform distribution of fracture positions, sizes, orientations and properties. Additional developments of the calculations and user interface could allow individual control and definition of the fractures. This would apply to both analytical and numerical models.

Use of microseismic information
The flexibility on fracture properties would make the problem even more under-defined than it is today. This could be compensated by the import of micro-seismic data in order to count, initialize and position the hydraulic fractures. Microseismics may also bring some large-scale information on the activated natural fracture network. This information may be used to calibrate new detailed fracture networks for the numerical model.

Multiphase flow
The simulation of the water flow back is one of the main unknowns that require multiphase modeling. This would only apply to the numerical model, and will imply accurate modeling of capillary effects, both in fractures and matrix.

Connection with hydraulic fracture simulation software
It is unlikely that the standard initialization of a two-phase simulation will properly address the problem of the water flow back. So, beyond the modeling of the diffusion itself, we will have to initialize the problem with a realistic hypothesis on where the water resides. The best possible start would be where the hydraulic fracture simulation ends. This would involve a mapping of the fracture simulation model and the reservoir model.

Multilateral fractured horizontal well
In densely populated areas, such as Western Europe, reducing the surface footprint will be one of the challenges for the acceptance of unconventional gas production. The use of multilaterals is going to be the most probable solution. The modeling of such wells will be done both analytically and numerically.

Exotic diffusion models
Many additional diffusion effects could be added in the numerical model. One of the goals of the consortium will be to implement those which make sense:
- Klinkenberg effect
- Knudsen diffusion
- Stress dependence in both fracture and reservoir (with different parameters)
- Other desorption isotherms
- Multiple porosities

Fracture patterns and multilayer modeling
Additional regular or random fracture patterns could be added in complement of the modeling of multiple producing layers. All this would be implemented in the numerical models, while only simpler geometries would be added to the analytical models. One objective is to characterize the impact of the secondary (natural) fracture network. Numerical models will handle various representations, from very detailed (random) discrete fracture models to effective multiple-porosity models, in order to allow scenario testing and calibration.

Beyond shale gas
A list of specific developments will be added for
- Coalbed Methane
- Shale Oil
- Hydrates

These subjects will be addressed in more detail in the next version of this document

Regression and statistics
We will also consider the relevance of uncertainty analysis and history matching data using experimental design and statistical runs using Monte Carlo Analysis.

G – Description of the KAPPA unconventional resources consortium

G.1 – Schedule

The present document will be sent by email to prospective members of the consortium. Prospective members will be asked to confirm their interest before **February 28th, 2011**.

Interested companies will be invited to a presentation meeting. Two sessions will be held in Houston (**March 2nd, 2011**) and in Sophia Antipolis (**March 8th, 2011**).

These sessions will be followed by a report and a Request-For-Comments (RFC) document where individual companies will provide expectations and list data that could be communicated to the consortium or to KAPPA only. RFC will have to be returned by **April 30th, 2011**.

On **May 31st, 2011** a final version of the technical and contractual documents will be delivered to the prospective members. Consortium members will be invited to sign and return the documents before **June 30th, 2011**.

This 18-month project will start on **July 1st, 2011**.

It should be completed by **December 31st, 2012**.

There will be six quarterly milestones, including a technical report of the work done and a **quarterly technical meeting** with videoconferencing in our US / UK / France offices. In the meetings the results of the previous period will be presented and discussed, potential new items will be brought and a list of priorities will be set for the next three months.

G.2 – Budget

KAPPA does not expect to profit directly from this consortium. KAPPA does seek an improvement to its software portfolio as result of the consortium. Administrative costs will be kept to a minimum and the commercialization of the consortium will not be taken from the consortium budget.

The estimated minimum budget for the consortium is **1,000,000 €** (one million euro). This represents 800 man-days of development. If the number of participants exceeds ten the additional budget will be allocated to additional development, preferably within the same global time frame

Accounting will be transparent. Every quarter consortium members will receive a financial update detailing the time and money spent per item.

The cost of the participation is **100,000 €** (one hundred thousand euro) **per company**, for any company joining the consortium before June 30th, 2011. This represented US$136,000 on 31st January, 2011. To assist member budget allocation this will be split over four equal payments of 25,000 € scheduled for (1) July 2011, (2) December 2011 or January 2012, (3) July 2012 and (4) December 2012 or January 2013. For payments (2) and (3) the choice of the month will at the discretion of individual consortium members.

Late participation will be possible after July 1st, 2011, for 125,000 € (one hundred and twenty five thousand euro). KAPPA will however have the right to waive the penalty for companies bringing specific experience and/or data to the consortium.

G.3 – Opt out option

We are confident that we will do what it takes to satisfy all consortium members. However, if a member is not satisfied by the developments of the consortium it will have the possibility to opt out of it by formally notifying KAPPA before the date of the next scheduled payment: December 31st, 2011; June 30th, 2012 and December 31st, 2012.

No further payment will be due. However KAPPA will not reimburse past contributions and the company opting out of the consortium will lose all benefits linked to its participation including continued use of the software (operational prototypes or commercial releases) specifically developed as a result of the consortium.

G.4 – Deliverables

Members of the consortium will have access to operational prototypes of our developments. These prototypes will be delivered for validation only, not for commercial purpose as they will not have gone through the systematic QA/QC applied to our commercial releases.

Commercial releases will also be available on a regular basis. A specific flag will be added to the software licenses of the consortium members. Any commercial license of Saphir NL, Topaze NL and Rubis owned by consortium member will get this additional flag, allowing the operation of the exclusive developments of the consortium.

G.5 – Exclusivity

Features developed for the consortium will be exclusive to the participants for a period of three (3) years from the date of the commercial release of the corresponding features.

This exclusivity will however be lifted for every feature that is available in one of our competitor's packages, in order to preserve the interests of our standard software users.

G.6 – Resources used to execute this consortium

In addition to its own resources, KAPPA will use the services of recognized technical authorities and academic institutions. Some fundamental research will be sub-contracted to research theses. KAPPA will also cooperate with software vendors from other disciplines as needed. The initial proposed list of KAPPA direct and indirect resources will be provided in the next version of this document.

G.7 – Intellectual Property

KAPPA will retain the intellectual and commercial property of the source code developed by this consortium.

This will not apply to source code written by contributing universities, which will be accessible to other members of the consortium if this is allowed under the policy of these universities.

For any intellectual property other than source code the policy of the consortium will be to publish any new findings in SPE publications and make these findings available to the industry.

H – How to register interest

If your company is interested in joining this consortium please let us know by sending a mail to unconventional@kappaeng.com. We will send you joining instructions in order for you to attend one of our meetings.