Science for Energy Scenarios

Les Houches, February, 2nd to 7th, 2014

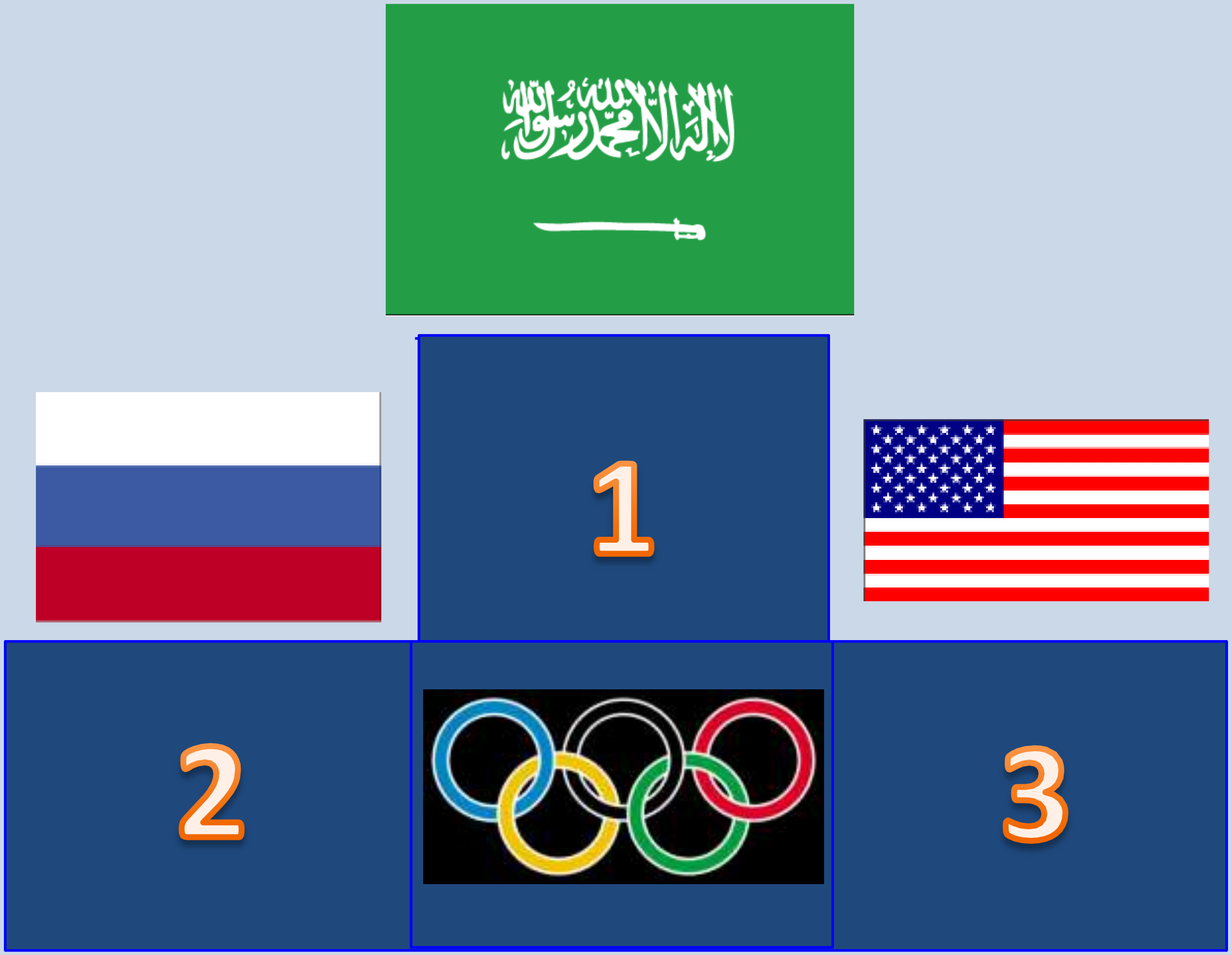
Fossil fuels reserves and resources, Geology & Production Potential

Daniel Chaussumier (ex. Total) / Roland Vially (IFP-Energies Nouvelles)

Outline

- The purpose of my talk is to describe the methodology used by the oil industry to predict the development of outputs.
- To set the scene, I will describe briefly the contribution of the fossil fuels in the global energy mix while recalling the peak oil theory.
- Then I will recap the various types of hydrocarbons accumulations.
- I will address the notions of recovery factor, of probability of success and define the different categories of resources.
- After that, I will explain briefly how production profiles are derived through the use of numerical simulation for conventional fields and other techniques for unconventional.
- To conclude I would like to remind you of the impact of the shale revolution in North America while emphasizing the uncertainty regarding predictions.

Quizz #1 : liquid hydrocarbon production in 2012



dc - February 5th 2014

Quizz #2 : ultimate resources of liquid hydrocarbons in 2012

Quizz #3: which country has the greatest gas production potential?

- From 2000 to 2070, first and second are USA and Russia.
- Which is 3rd ?
  - From 2000 à 2010
  - In 2013
  - From 2020 to 2040
  - From 2050 to 2070
- Which was 4th in 2000 ?

Canada

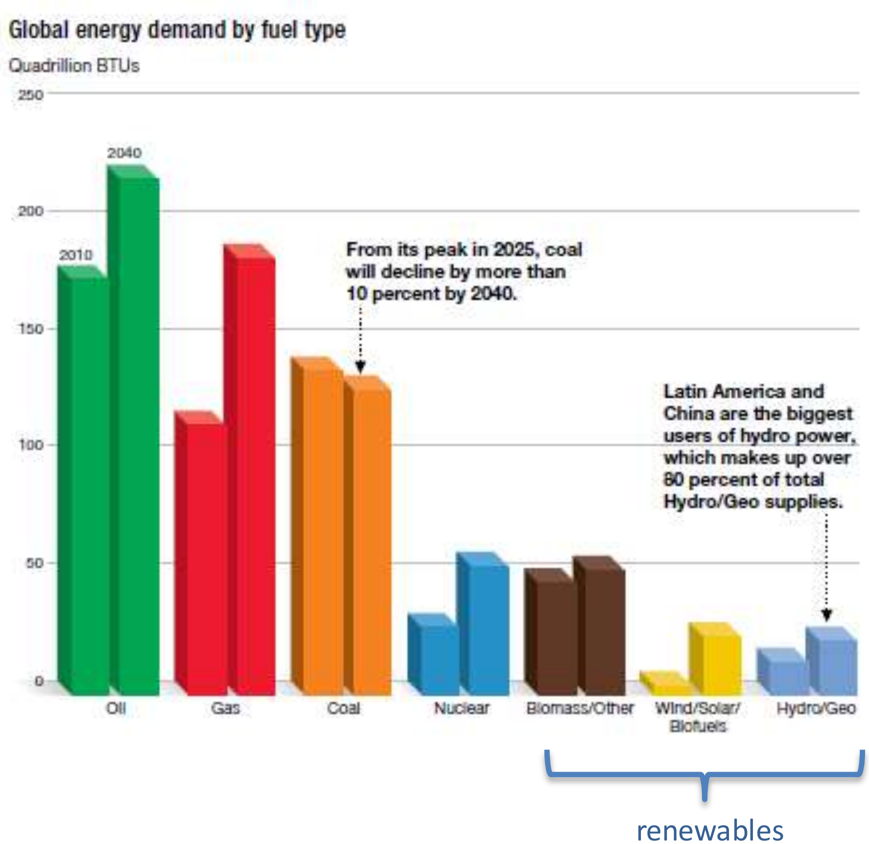
Qatar

China

Iran

UK

Evolution of the energy mix between 2010 and 2040



- energy demand increases by 30%
- gas (+60%) replaces coal in the second place

Source : XOM 2012

International Energy Agency scenarios

- Current Policies Scenario takes into consideration only those policies that had been formally adopted .

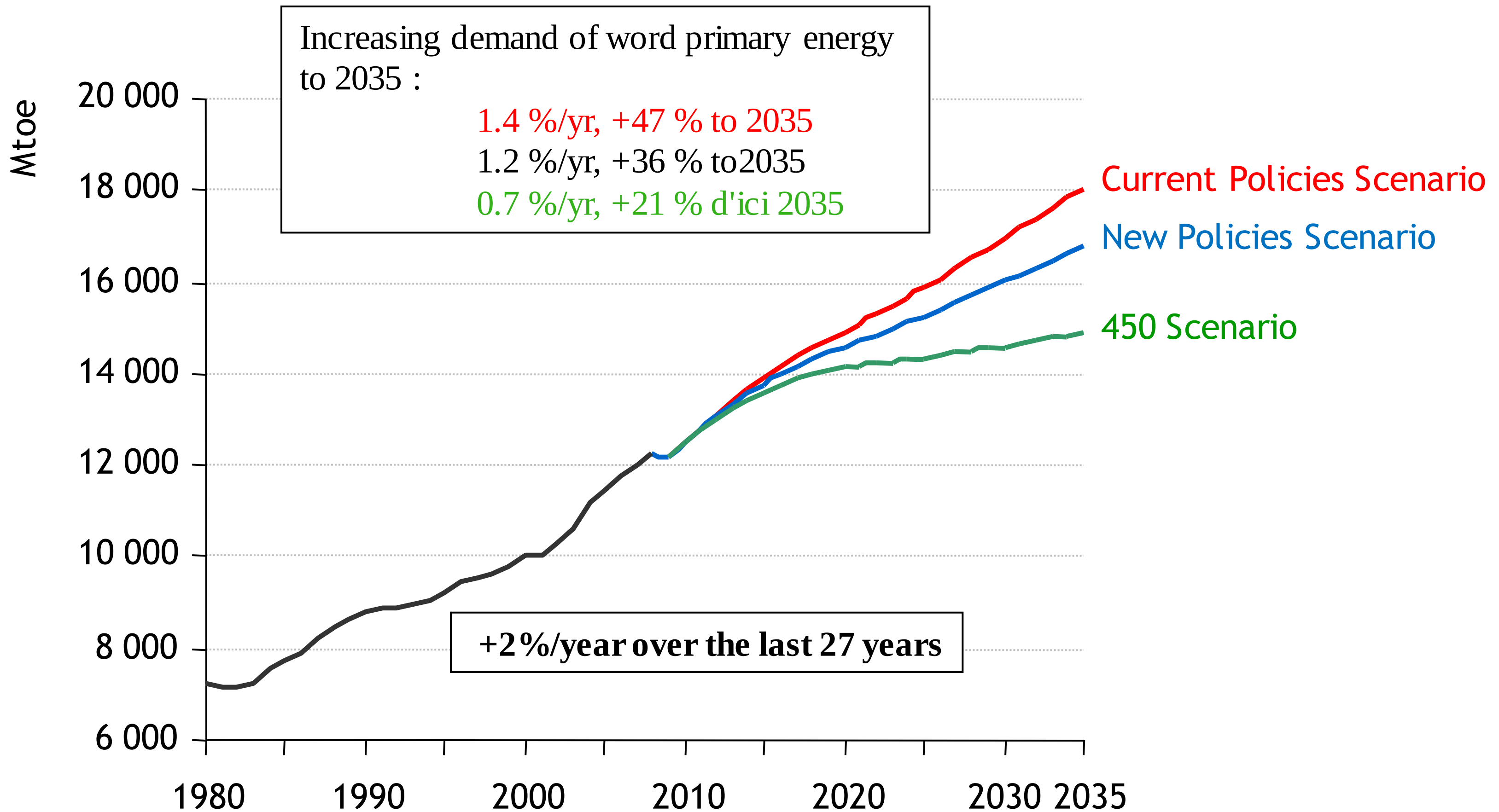
- *New Policies Scenario* is the central scenario

  - *assumes cautious implementation of recently announced commitments & plans, even if yet to be formally adopted*

  - *provides benchmark to assess achievements & limitations of recent developments in climate & energy policy*

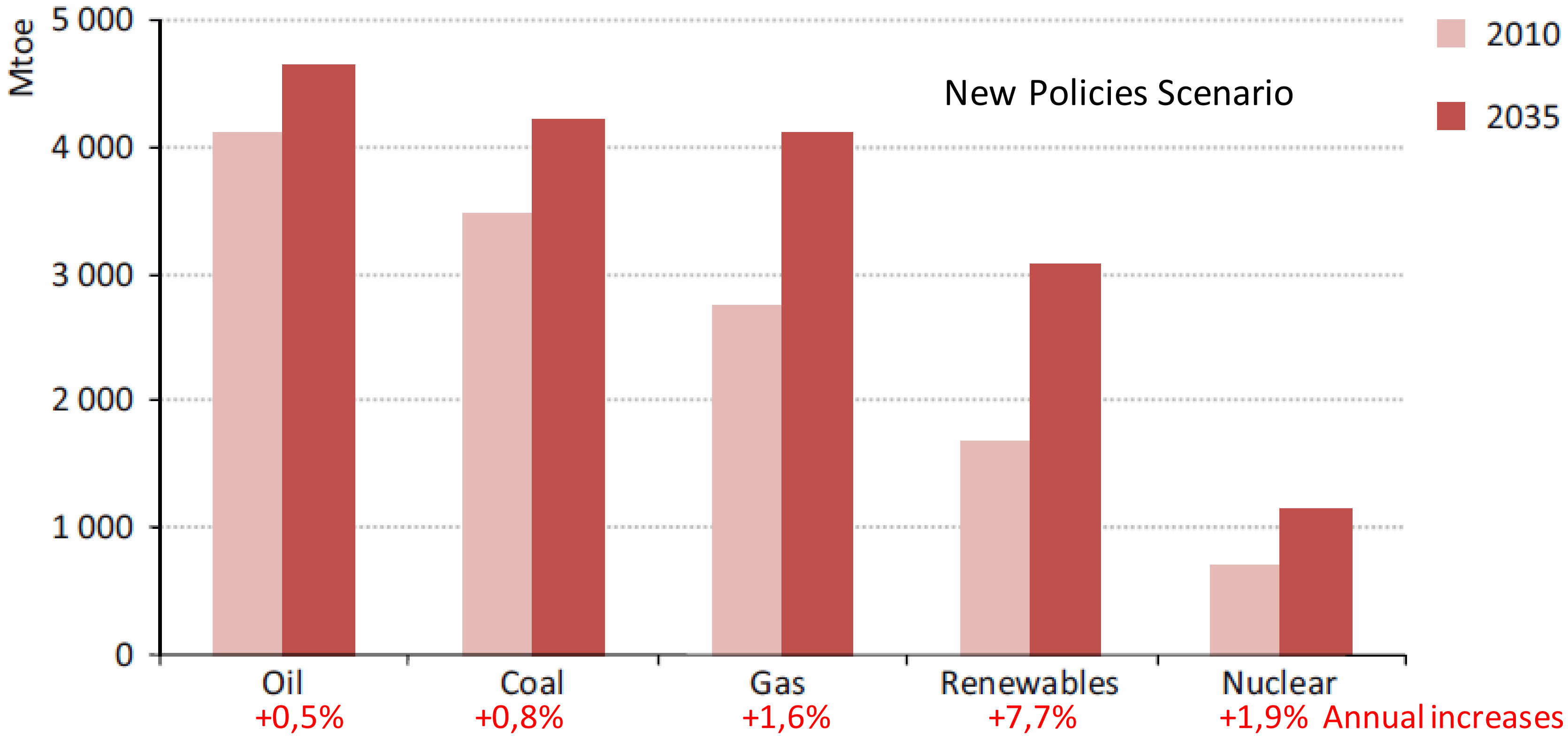
- The 450 Scenario sets out an energy pathway consistent with the goal of limiting increase in average temperature to 2^{O}C

Increasing demand of world primary energy



In 2035, energy demand is 8% higher in the Current Policies Scenario and 11% lower in the 450 Scenario than in the New Policies Scenario

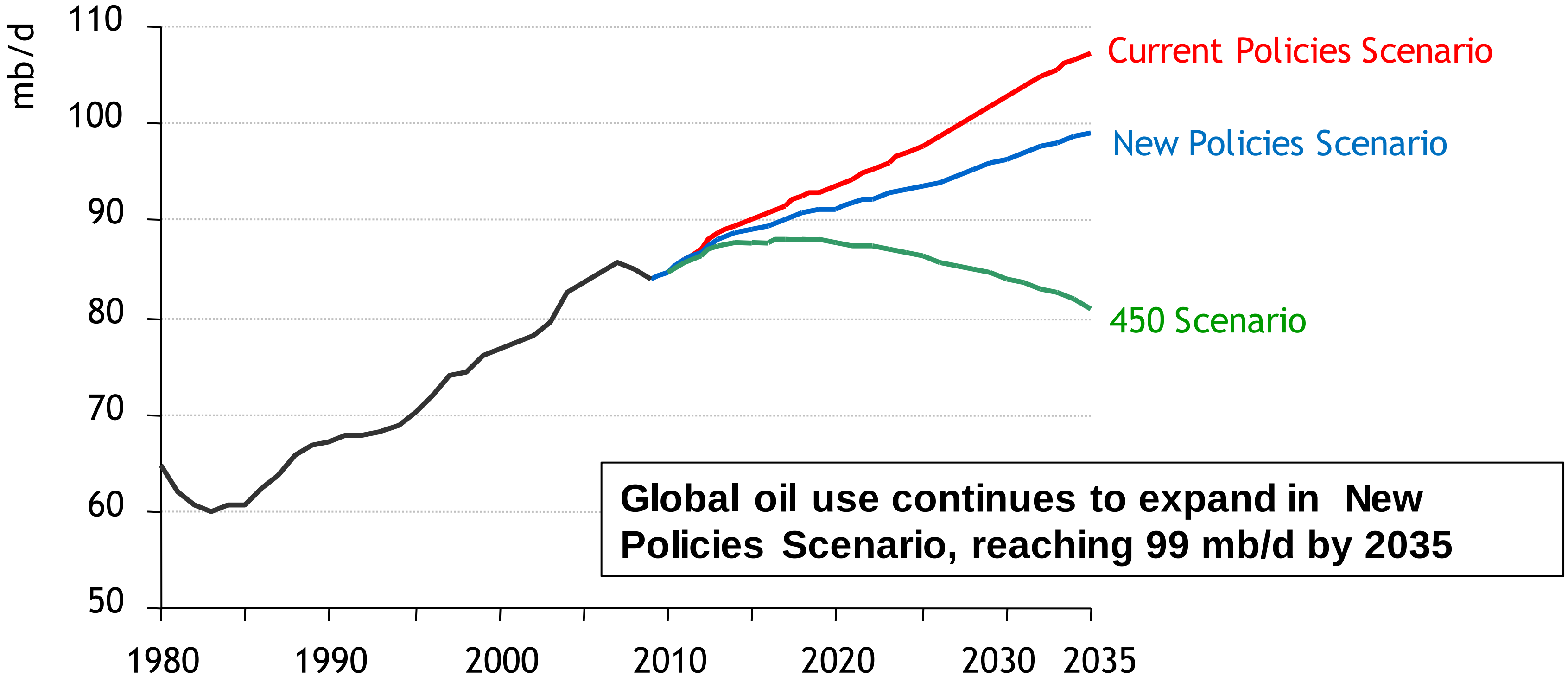
World primary energy demand by fuel (NPS)



Proportion of hydrocarbons (oil + gas) in the global energy mix

1990 : 56% 2010 : 54% 2035 : 51%

Global oil use continues to expand.

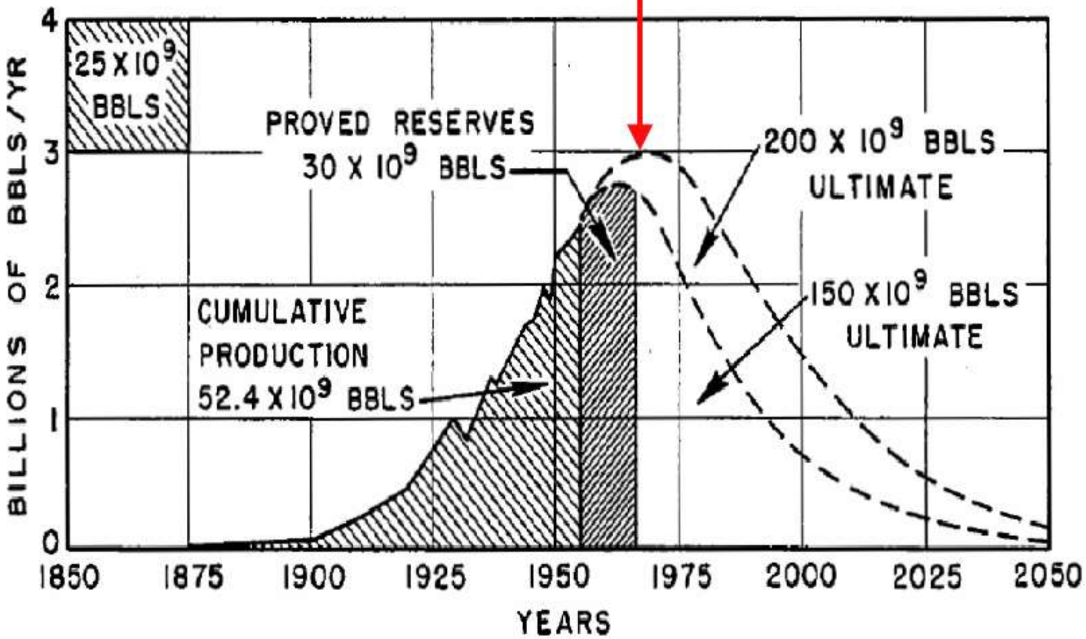


The fundamental question:

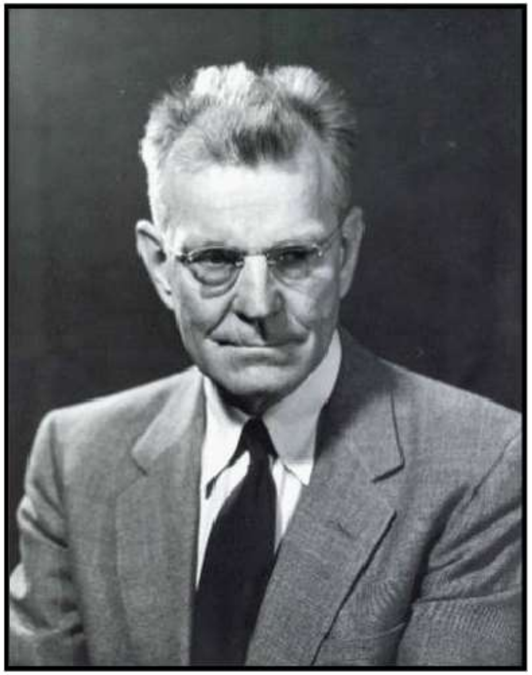
Will liquid hydrocarbons resources be sufficient?

« Peak-oil » theory.

USA peak-oil forecast : 1970



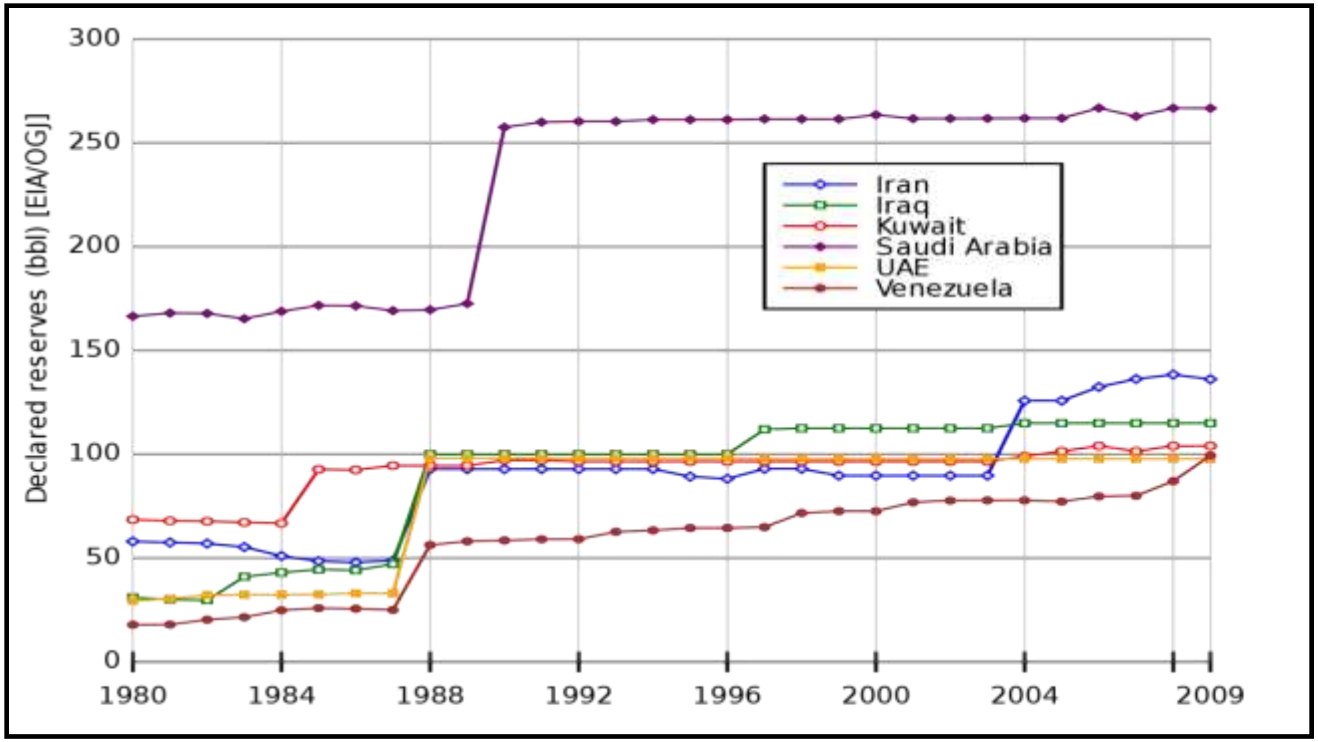
US predicted oil production from Hubbert theory
(Hubbert, 1956)
US peak-oil occurs in 1971



KING HUBBERT
Géophysicien chez SHELL

Production begins to decline when half
of the Ultimate Recoverable Resources are produced

PROVEN RESERVES …. not sure



In many countries (corresponding to 80% of the volume of reserves) the reserves are not certified by an independent institution …
In 1987, a reassessment of 300 billion barrels in less than 6 months appeared to be *"suspicious“..*
Has peak-oil already been reached ?

NEW POLICIES SCENARIO
Implication in term of resources

Recap on the various Oil & Gas fields

- Conventional
  - The hydrocarbons generated by maturation of the source rock have migrated into a **reservoir** (porous & permeable medium) and accumulated in a **geologic trap**.
- Unconventional
  - No migration: residual hydrocarbons in the source rock (shale oil and shale gas), permeability ~ 0
  - No geologic trap: Basin Centered Gas, oil sands, methane hydrates, mobility ~ 0
  - No maturation: oil shale

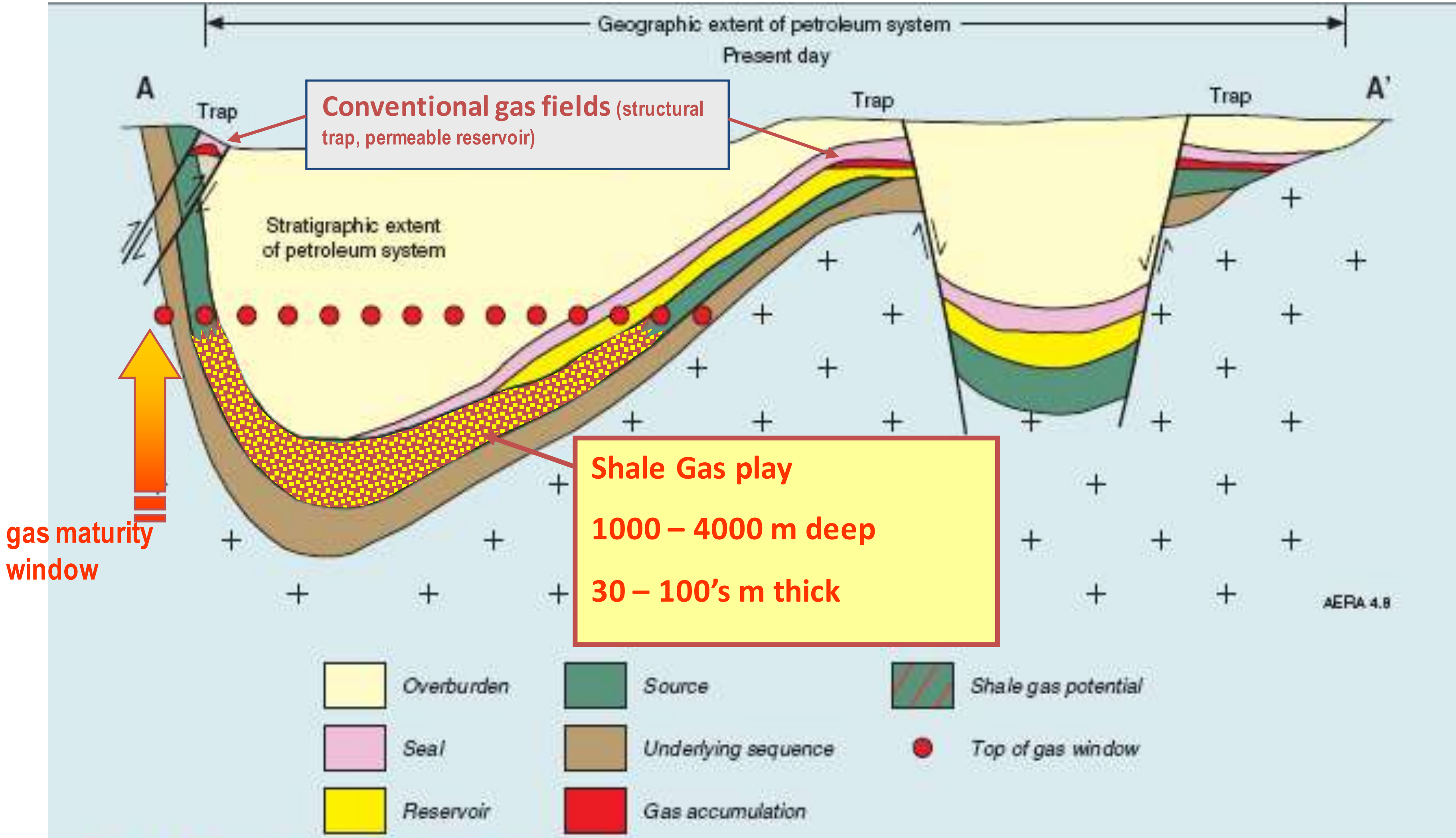
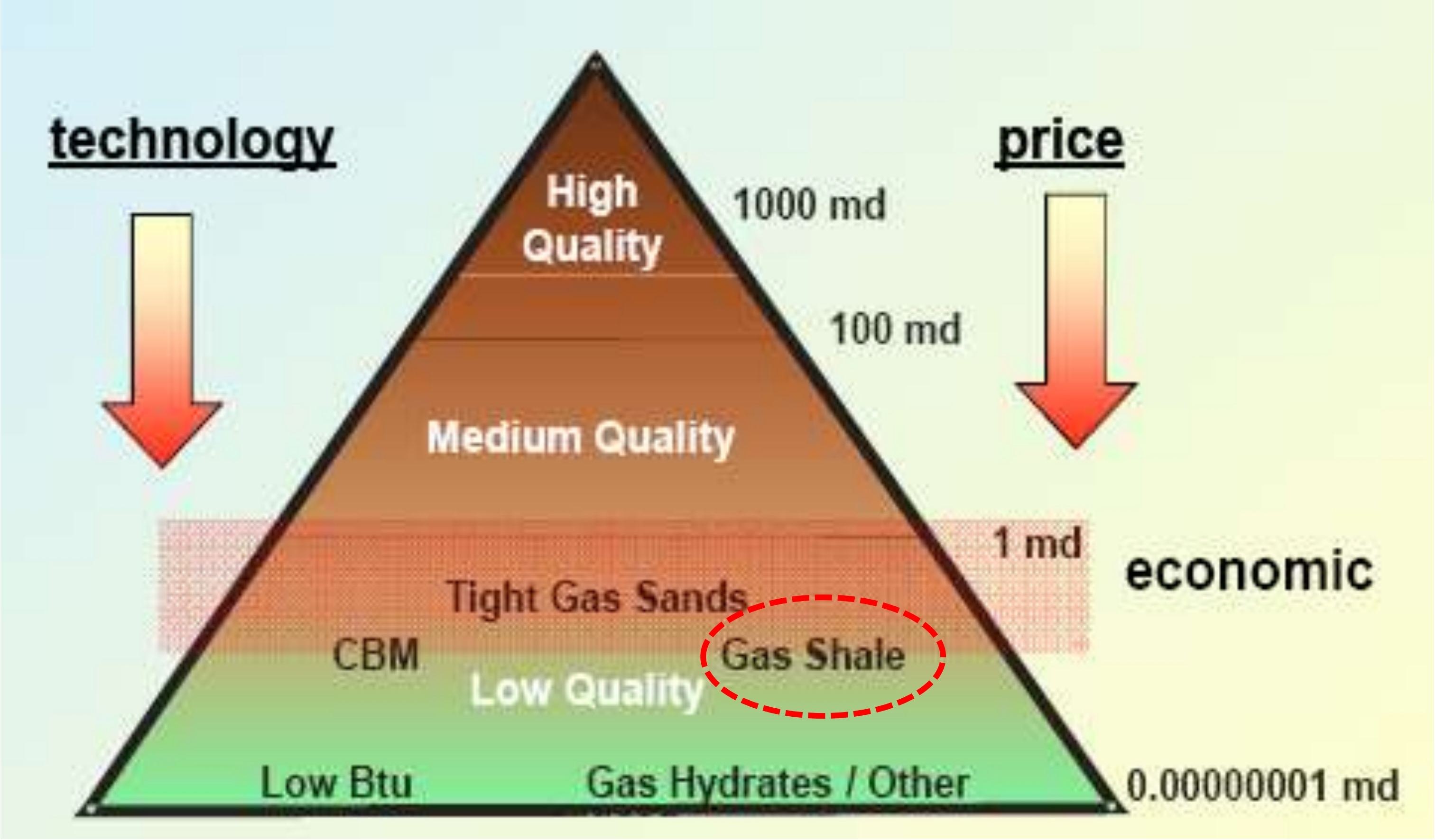


Figure 4.8 Petroleum system elements

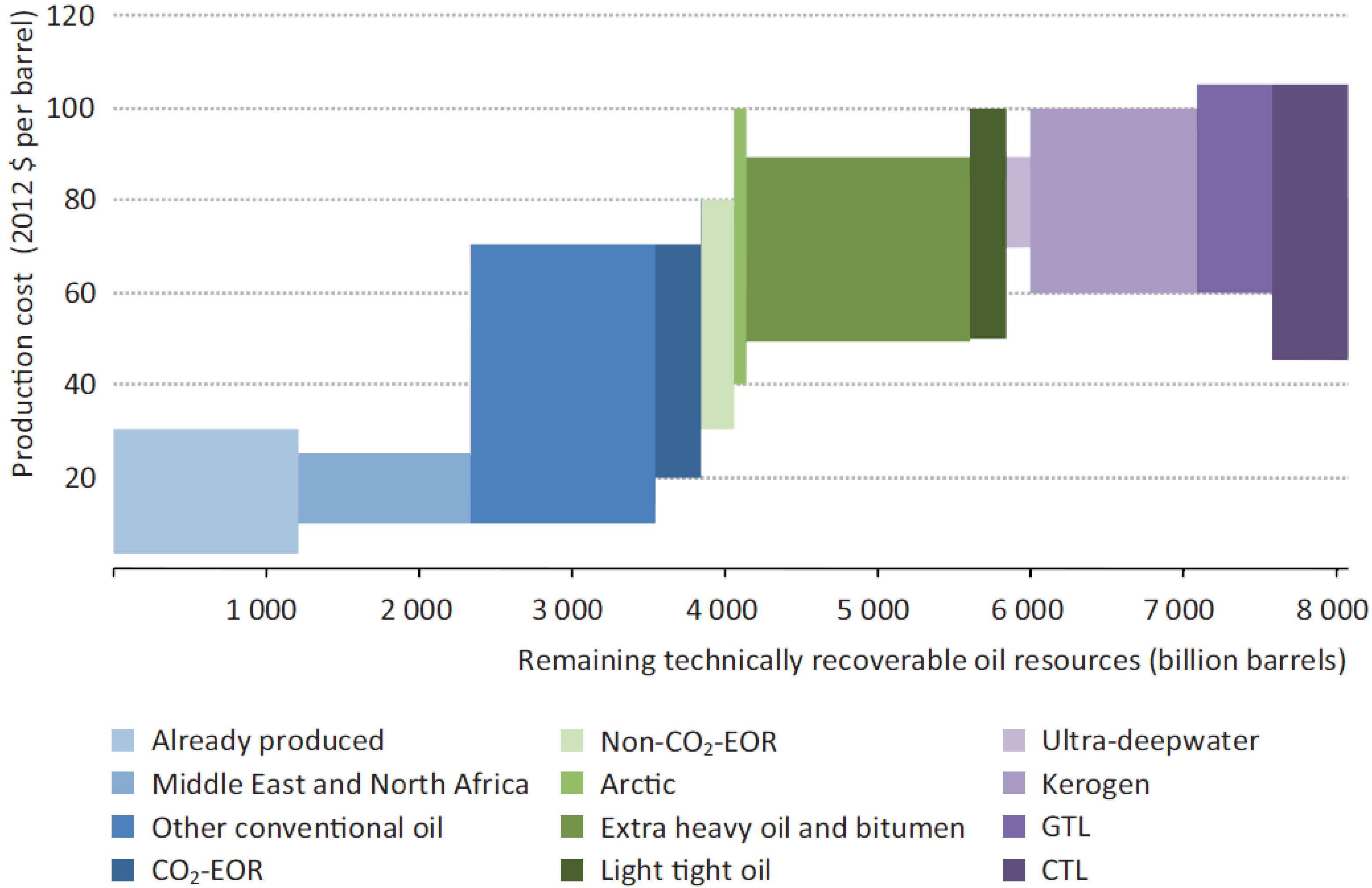
Source: Modified after Magoon and Dow 1994

Ressource triangle

The concept of the resource triangle (Figure 2-1) has often been used to describe the distribution of resources in nature. The triangle illustrates that there are relatively few high quality reservoirs but a larger number of poorer quality. These lower quality reservoirs, however, can be larger than the conventional reservoirs but require superior technology or increased prices to extract commercially.



Supply cost of liquid fuels



Source: *Resources to Reserves* (IEA, 2013).

Recovery Factor (RF)

- Proportion of the accumulation that can be extracted from the ground
- Typical values:
  - Conventional oil fields : from 5% to 60%, average = 30%
  - Conventional gas fields : from 20% to 90%, average = 75%
  - Shale oil : ca 7% in the SRV
  - Shale gas : ca 20% in the SRV

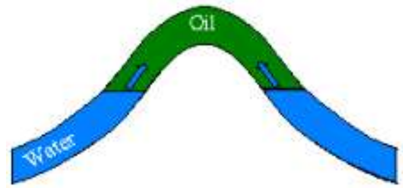
Reserve and Resource = accumulation x RF

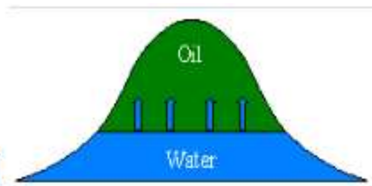
Main factors affecting RF of conventional fields

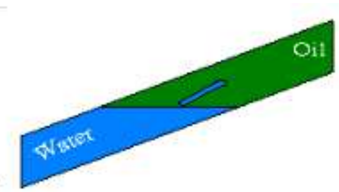
- Reservoir properties
  - Porosity (φ)
  - Permeability (k)
  - Geometry (thickness, dip, compartmentalization)
- Fluid properties
  - Hydrocarbon saturation and initial pressure
  - Hydrocarbon compressibility (FVF, saturation pressure)
  - Hydrocarbon viscosity (μ)
- Economic conditions
  - CAPEX (wells, surface facilities, evacuation)
  - OPEX and royalties
  - Gas price

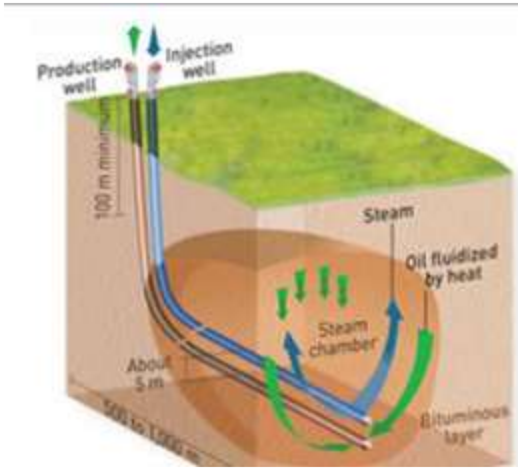
Recovery mechanisms for conventional fields

- High compressibility (gas):
  - Natural depletion
- Low compressibility (oil):
  - High aquifer activity: natural depletion
  - Low aquifer activity: water or gas injection
- Low mobility (k/µ)
  - High µ (viscous oil): steam injection, polymer injection
  - Low k (tight gas): hydraulic fracturing and horizontal drilling







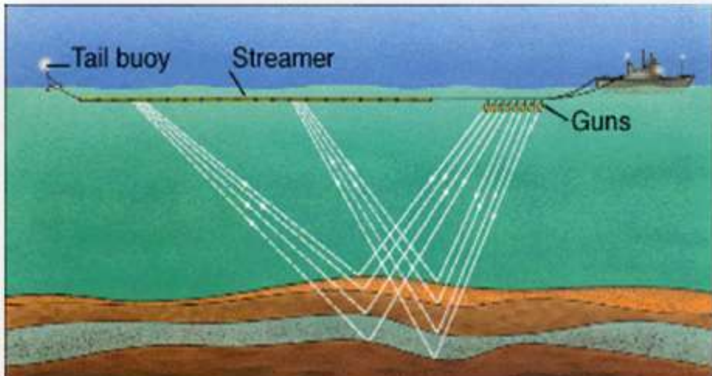


How to derive RF (conventional oil field)?

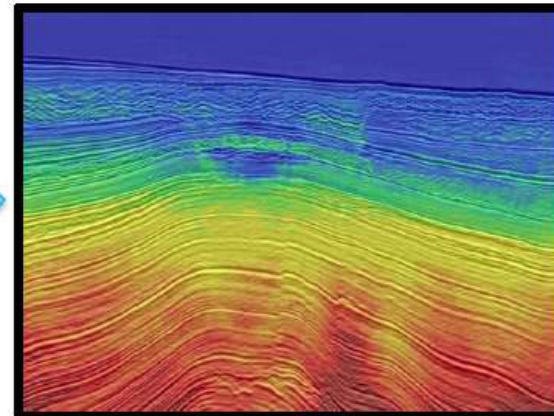
1. Depending on available data, construction of a geologic model
   - Fine grid to capture the reservoir heterogeneity (core and log data)
   - Structure and compartmentalization defined using seismic data
2. Construction of a dynamic model
   - Upscaling of the geologic model
   - Analysis of well tests and production data
3. Validation of the dynamic model
   - Match of the production history: well performance, pressure monitoring, fw and GOR development
4. Predictions
   - Input of the production constraints: WHFP, economic cut-off

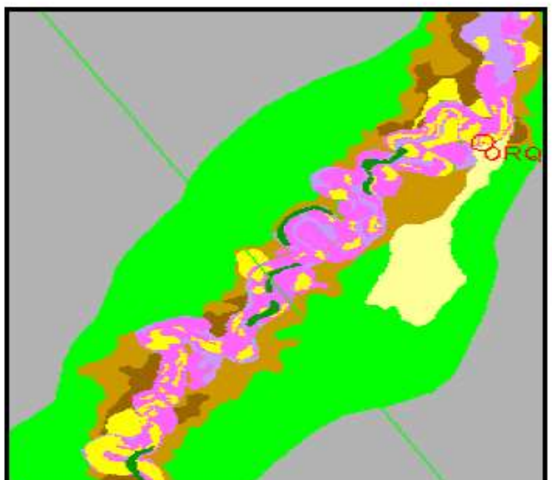
RESERVOIR SIMULATION IN THE GEOSCIENCES CHAIN

Seismic processing and imaging

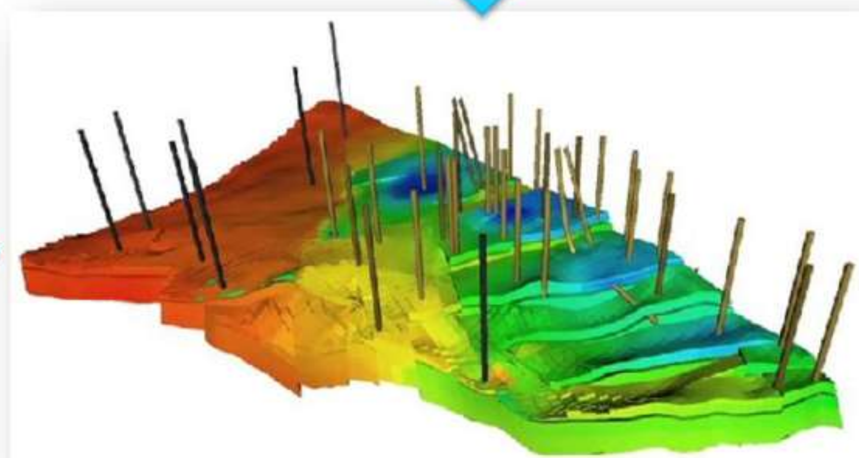


Create an image of the subsurface from reflections recorded at the surface

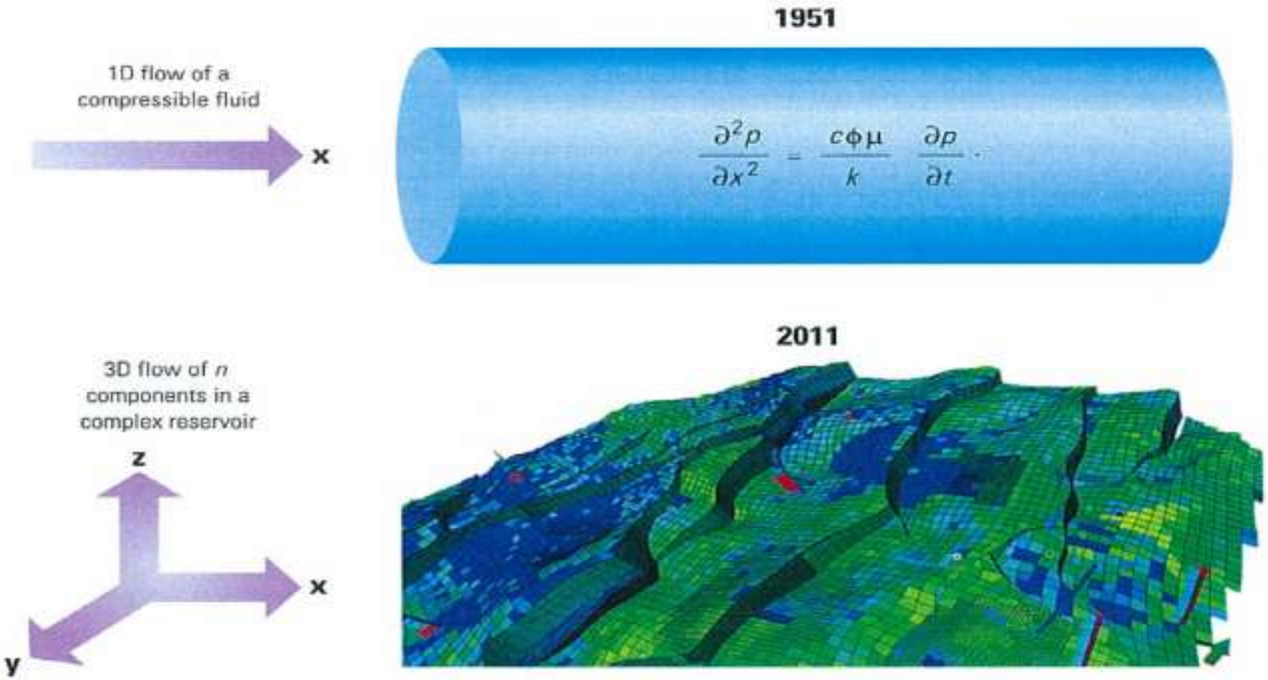




Geological interpretation

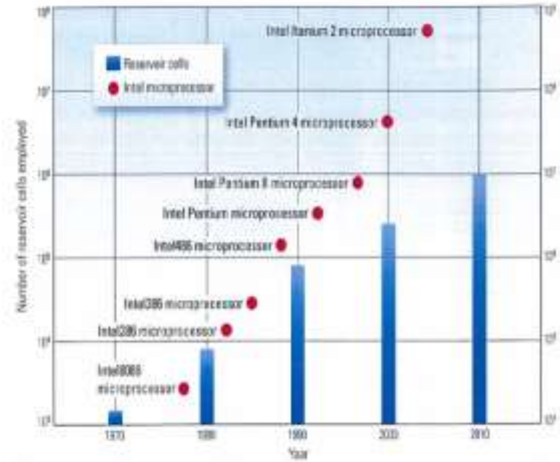


A gridded geomodel for flow simulation



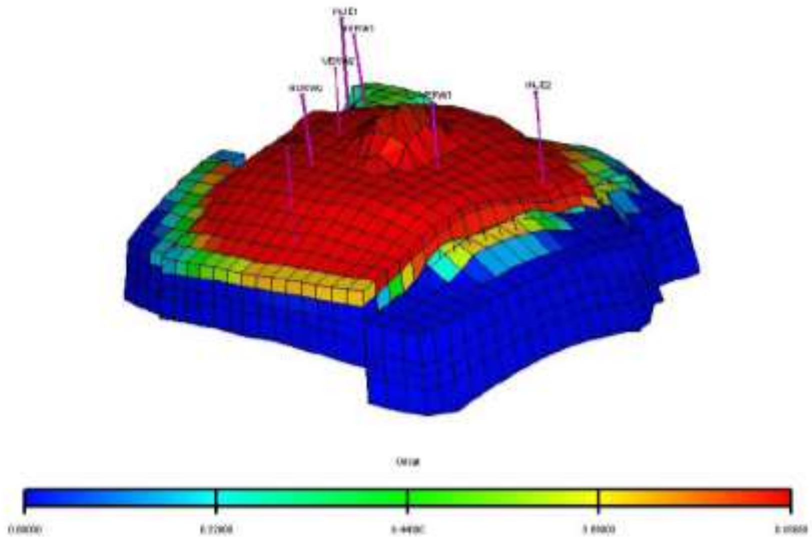
$$\frac{V}{\Delta t}\,\delta\left(\phi\sum_{p}^{Np,c}\rho_p S_p \chi_{cp}\right) + q_c^W - \sum_{k}^{Faces} T_k\left\{\sum_{p}^{Np,c}\left[\rho_p \frac{k_{rp}}{\mu_p}\chi_{cp}\left(\Delta p - \Delta Pc_p - \rho_p g \Delta h\right)\right]\right\} = R_c.$$

^ Reservoir simulation evolution. One of the first attempts to analytically describe reservoir flow occurred in the early 1950s. Researchers developed a partial differential equation to describe 1D flow of a compressible fluid in a reservoir (*top*). This equation is derived from Darcy's law for flow in porous media plus the law of conservation of mass; it describes pressure as a function of time and position. (For details: McCarty DG and Peaceman DW: "Application of Large Computers to Reservoir Engineering Problems," paper SPE 844, presented at a Joint Meeting of University of Texas and Texas A&M Student Chapters of AIME, Austin, Texas, February 14–15, 1957.) Recent models developed for reservoir simulation consider the flow of multiple components in a reservoir that is divided into a large number of 3D components known as grid cells (*bottom*). Darcy's law and conservation of mass, plus thermodynamic equilibrium of components between phases, govern equations that describe flow in and out of these cells. In addition to flow rates, the models describe other variables including pressure, temperature and phase saturation. (For details: Cao et al, reference 6.)

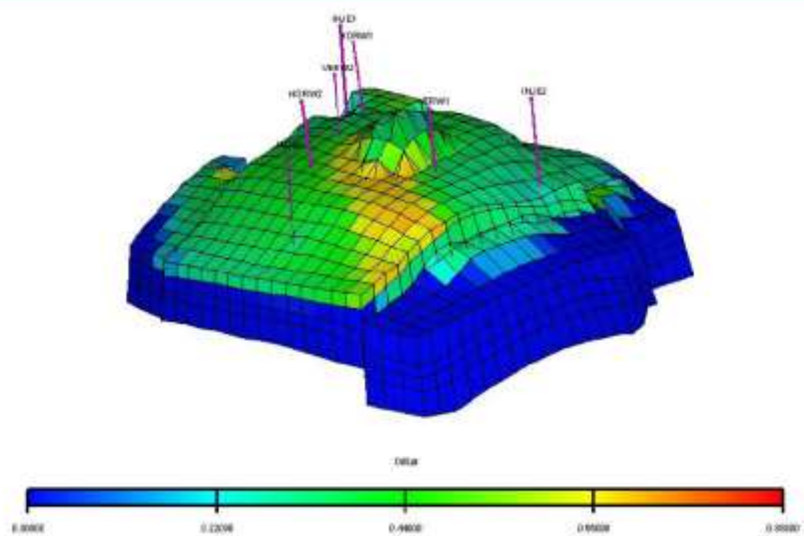


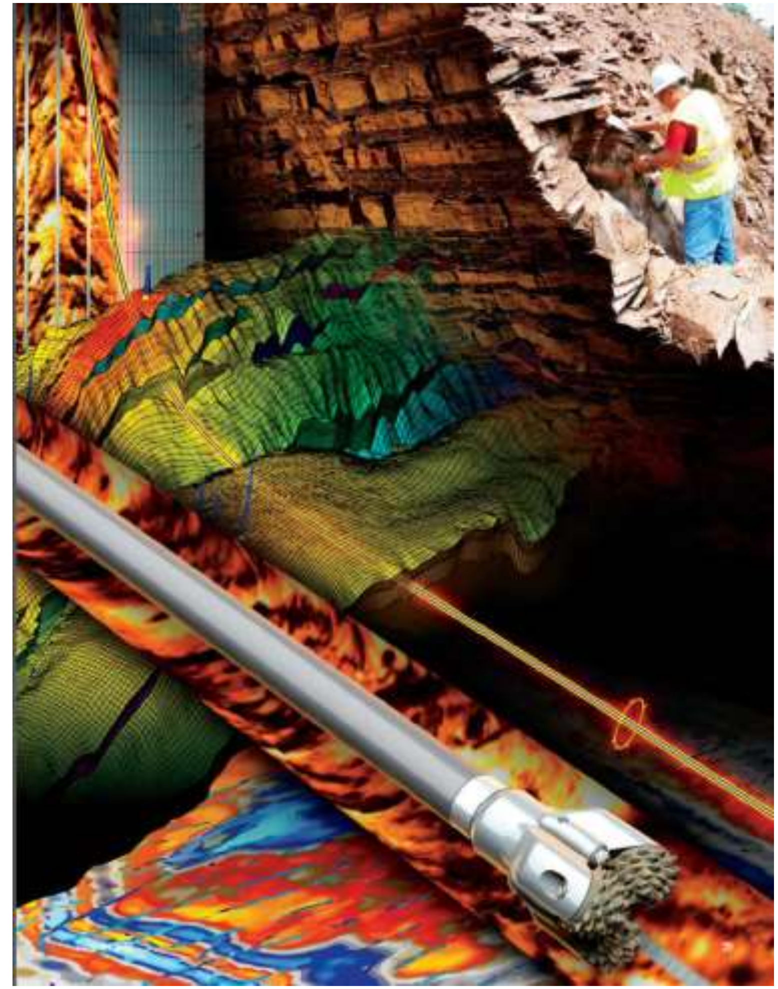
^ Computing capability and reservoir simulation. During the past four decades, computing capability and reservoir simulation evolved along similar paths. From the 1970s until 2004, computer microprocessors followed Moore's law, which states that transistor density on a microprocessor (red circles), doubles about every two years. Reservoir simulation paralleled this growth in computing capability with the growth in number of grid cells (blue bars) that could be accommodated. In the last decade, computing architecture has focused on parallel processing rather than simple increases to transistor count or frequency. Similarly, reservoir simulation has moved toward parallel solution of the reservoir equations.

DOME (FFM): Initial Oil saturation



DOME (FFM): Final Oil saturation





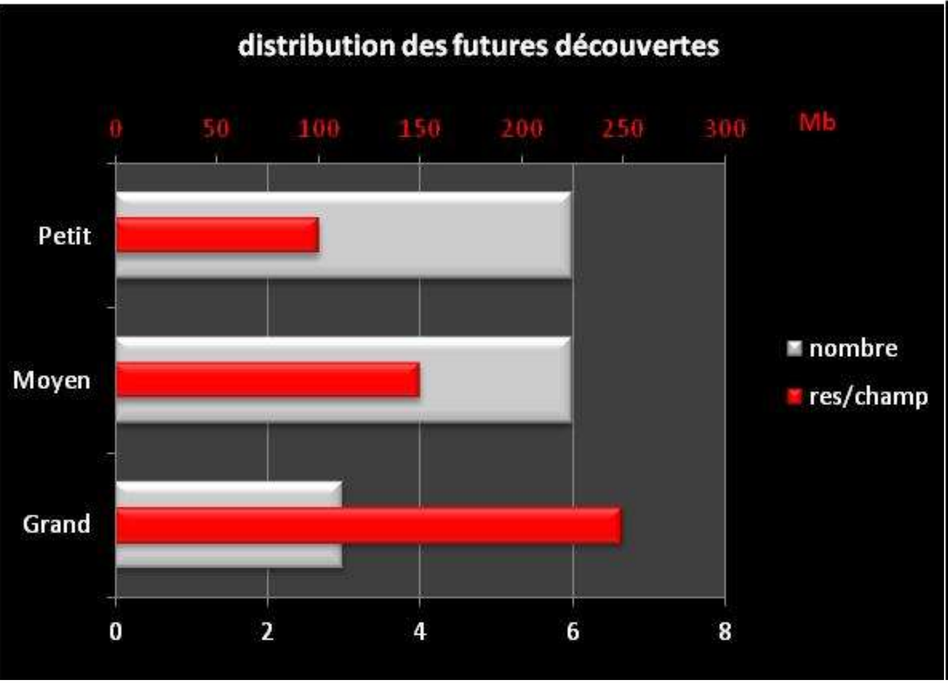
Production profile for undiscovered oil fields

Resources = assumption

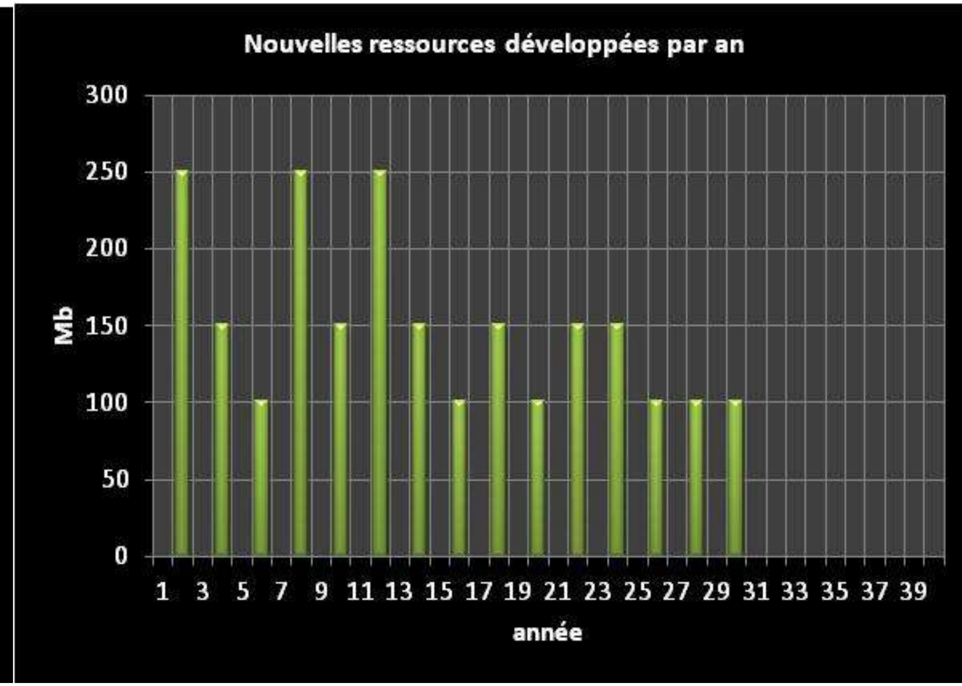
Use of typical production profiles (dimensionless)

Example

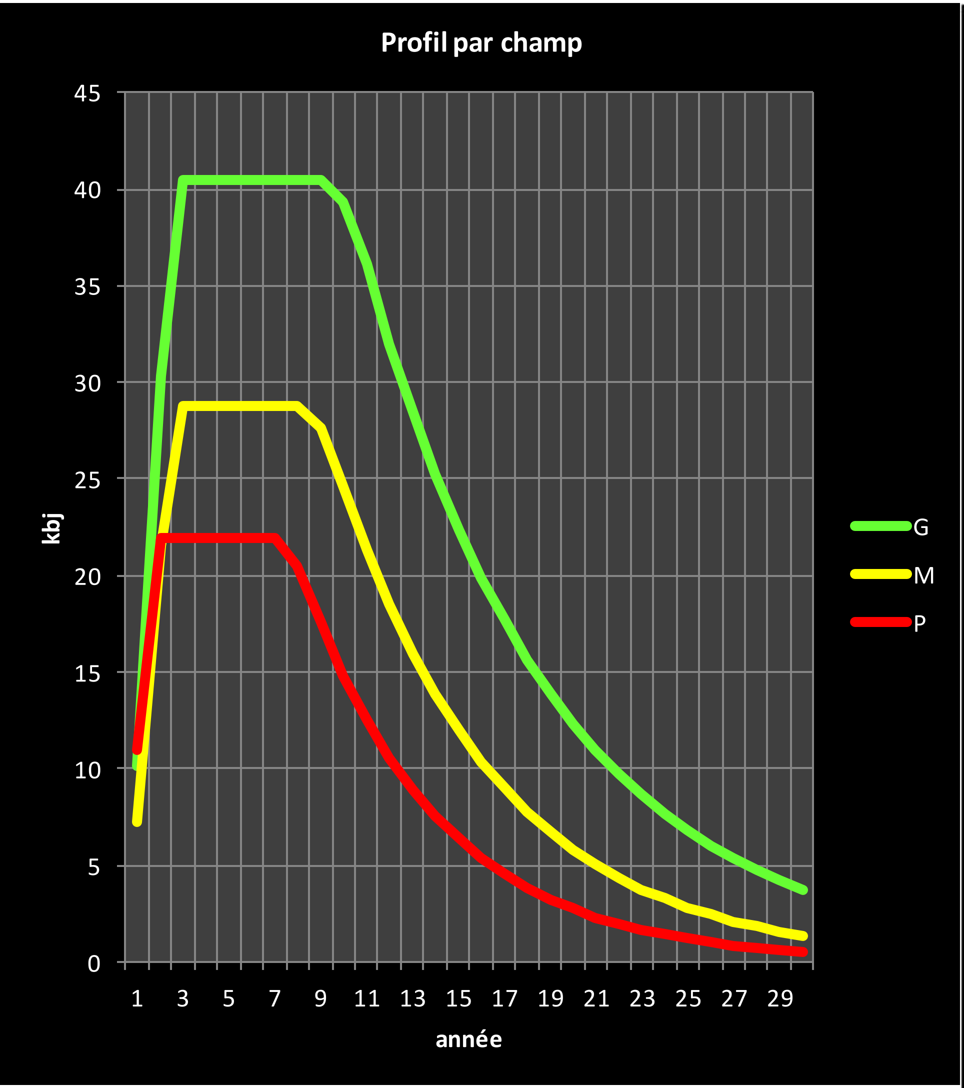
- Total exploration resources (eg 2.25 Gb)
- Number of fields (eg 15)
- Maximum size of a field (eg 250 Mb)
- Time frame to complete the exploration profile (eg 30 years)



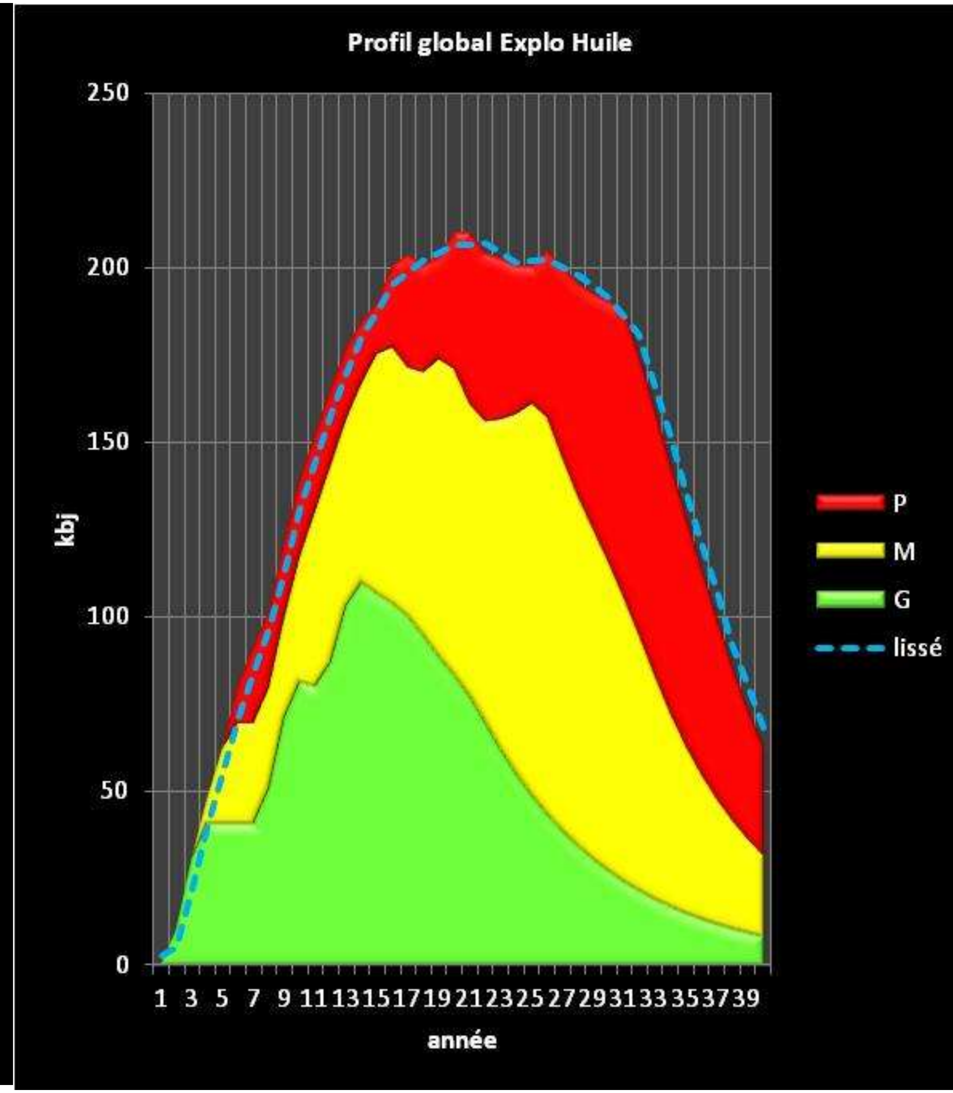
distribution des futures découvertes
0
50
100
150
200
250
300
Mb
Petit
Moyen
Grand
nombre
res/champ
0
2
4
6
8



Nouvelles ressources développées par an
300
250
200
150
100
50
0
Mb
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39
année



Profil par champ
45
40
35
30
25
20
15
10
5
0
kbj
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
année
G
M
P

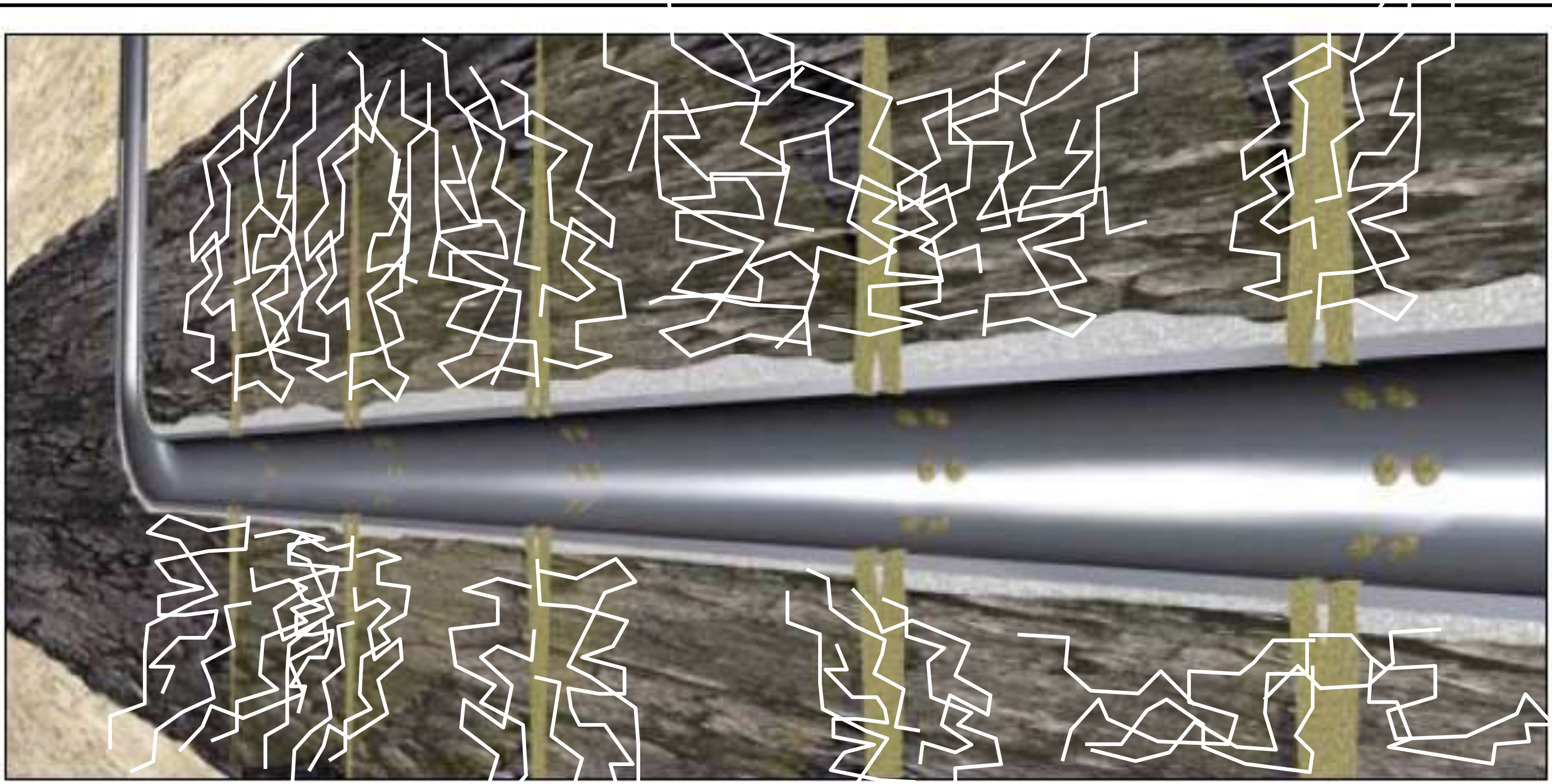


Profil global Explo Huile
250
200
150
100
50
0
kbj
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39
année
P
M
G
lissé

How to derive RF (shale gas field)?

1. Mapping of the source rock
   - Cut-off on depth and thickness
   - Maturity map to determine oil and gas windows
2. Calculation of the HIP density
   - TOC, thickness, porosity, pressure
3. Elaboration of a development plan
   - Wells count and lay out taking topography into account (no drilling in urbanized areas, national parks, lakes, etc)
4. Predictions
   - Combination type curve x drilling planning

Permeability created in the SRV by hydraulic fracking



- ✓ **horizontal drains from 1000 to 1500 m**
- ✓ **up to 16 frac stages**
- ✓ **injection of 16000 m3 of water and 1500 t of sand**

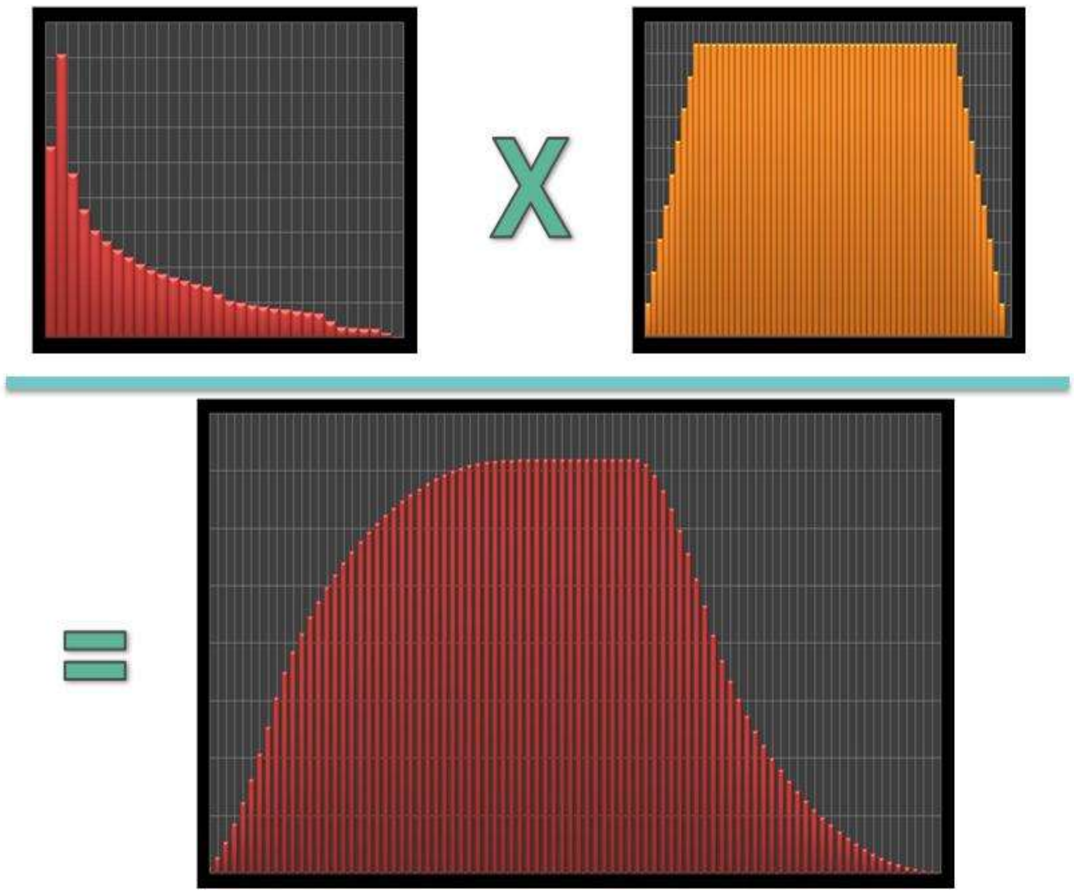
Fracture Stimulation in Gas Shale Play Type

Shale Gas well after tie in

Production profile for unconventional

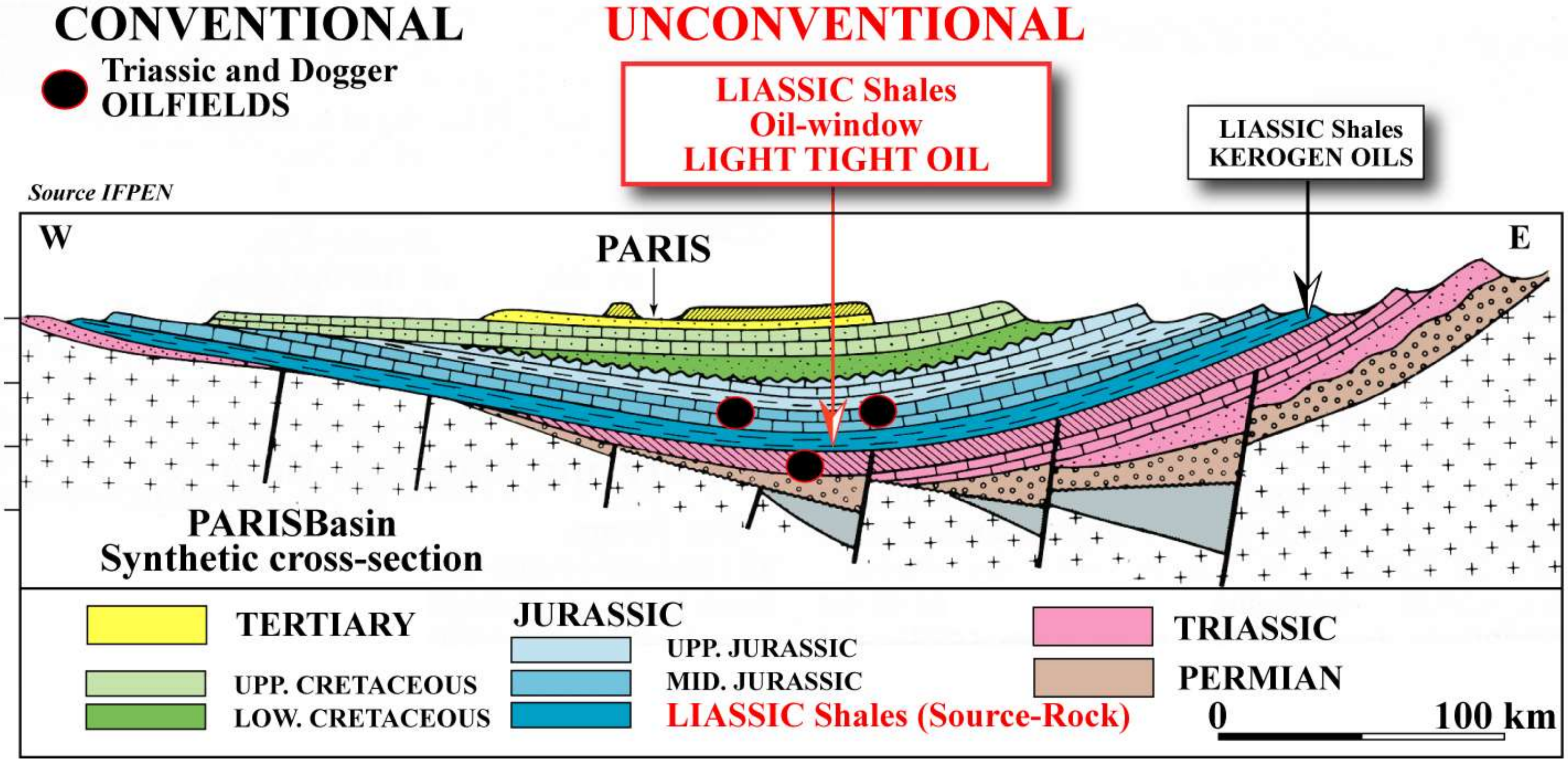
- permeability close to 0 ➔ no interference between wells
- Consequences :
    - Resources proportional to well count
    - Production profile tied to the drilling planning (<u>additional uncertainty</u>)

  – Risked resources = high quantities x low PS
- Consequences :
    - High sensitivity to PS choice



Basin modelling

The evaluation of the Light Tight Oil in the Paris Basin (1)



Basin modelling

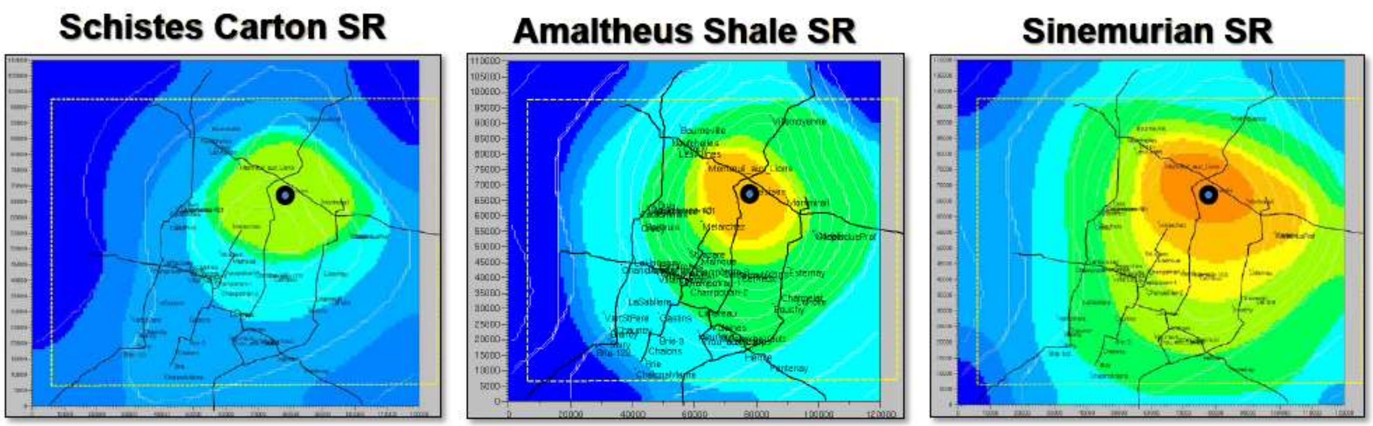
The evaluation of the Light Tight Oil in the Paris Basin (2)

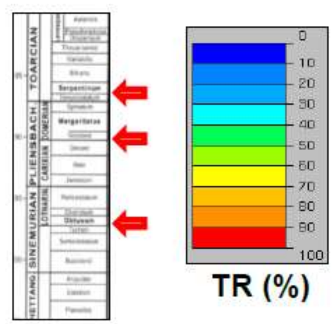
BeicipFranlab

TR maps updated with 2D modeling results

TOREADOR

Interpolation of Modeling Results



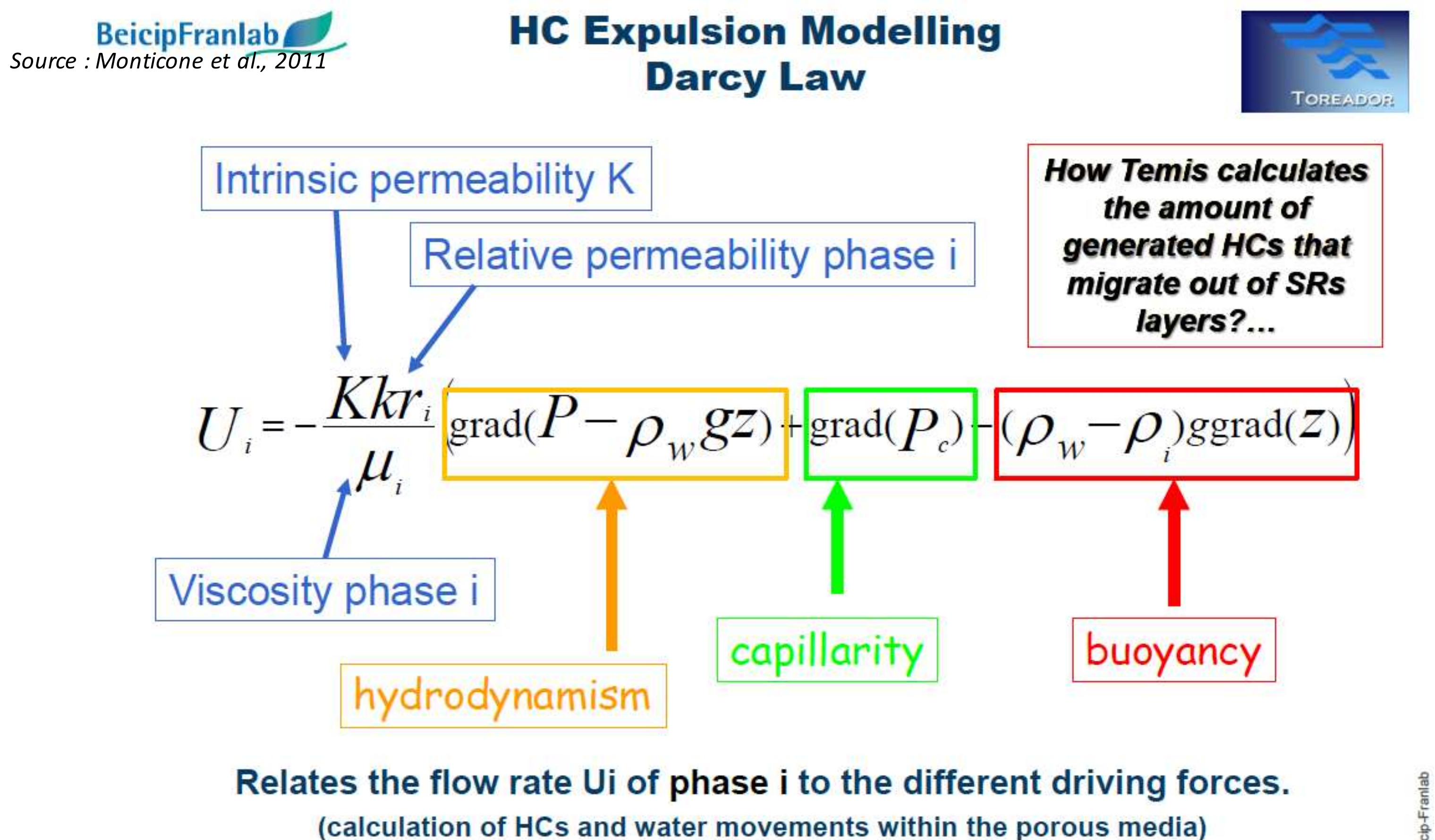


Source : Monticone et al., 2011

Basin modelling

The evaluation of the Light Tight Oil in the Paris Basin (3)

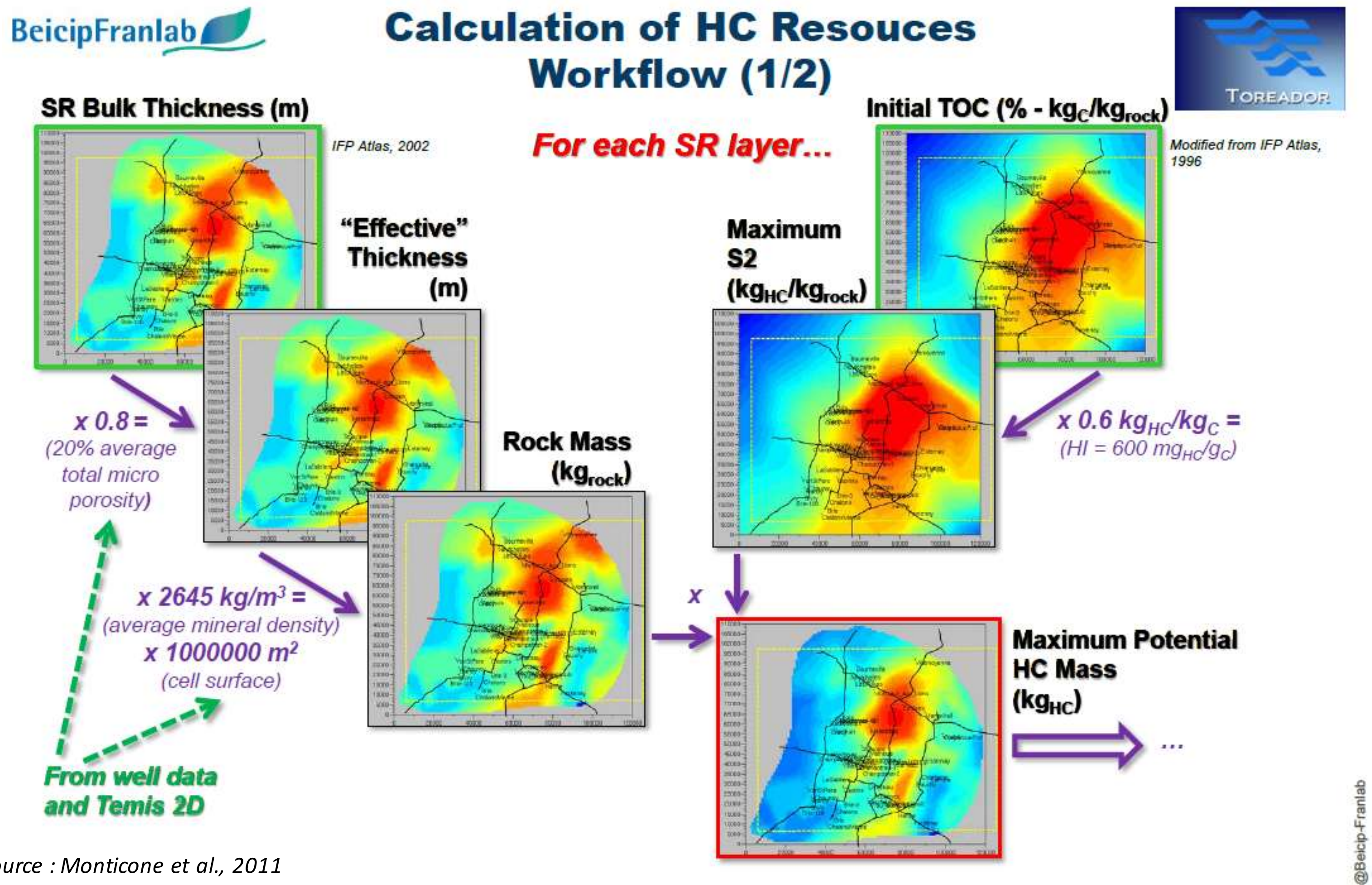
In conventional evaluation we are trying to quantify the expelled hydrocarbons



For LTO or shale gas we are trying to quantify the remaining hydrocarbons....

Basin modelling

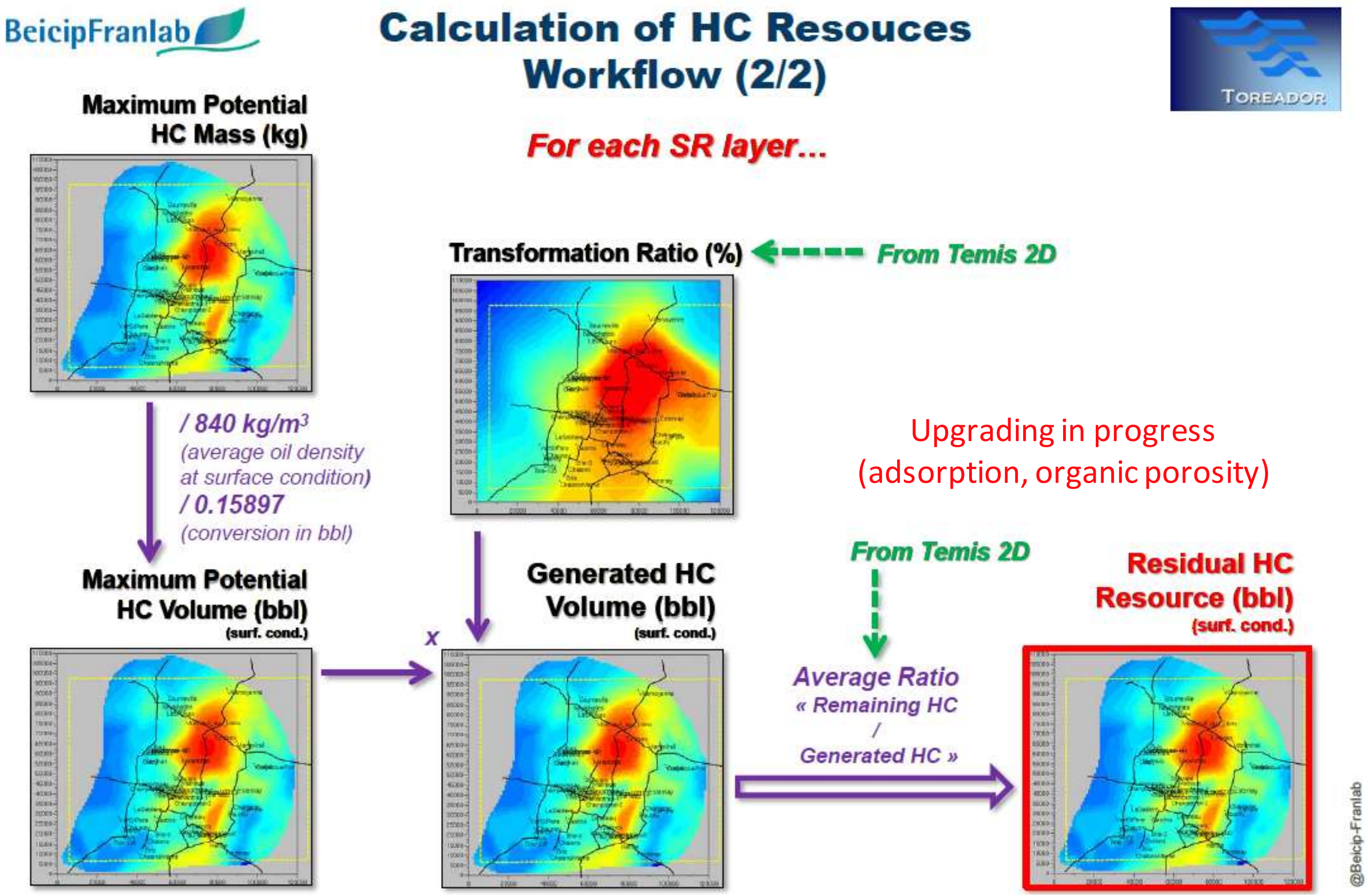
The evaluation of Light Tigh Oil in the Paris Basin (4)



Source : Monticone et al., 2011

Basin modelling

The evaluation of Light Tight oil in the Paris Basin (5)



Upgrading in progress
(adsorption, organic porosity)

Source : Monticone et al., 2011

Basin modelling

The evaluation of Light tight Oils in the Paris Basin (6)

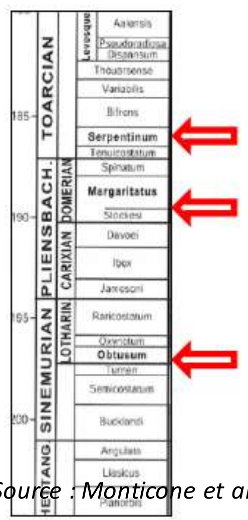
BeicipFranlab

Non-Expelled HC Resources in Source Rocks of the Paris Basin

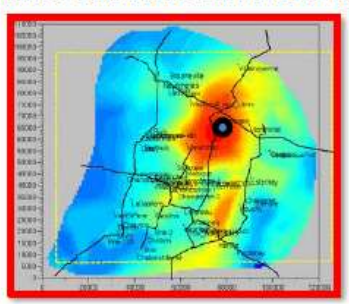
TOREADOR

	Generated HC volume (calculated with TR) Bbbl	**Residual HC resource in SR layers Bbbl**	TR average
SCHISTES CARTON SR	45	**9**	32%
AMALTEUS SR (Domerian)	11	**2**	43%
SINEMURIAN SR (Lotharingian)	24	**5**	58%
TOTAL Bbbl	**81**	**16**	

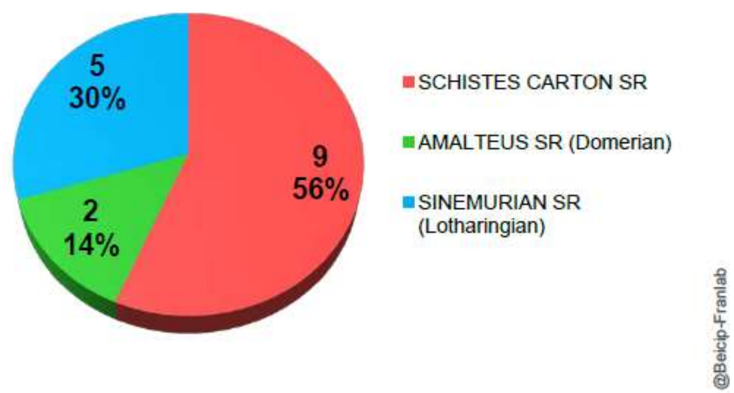
Recovery factor : 6% = 1 Bbbl ! in the PARIS BASIN



Volume calculated on 9 521 km².



Residual HC resource in SR layers
Bbbl - % total



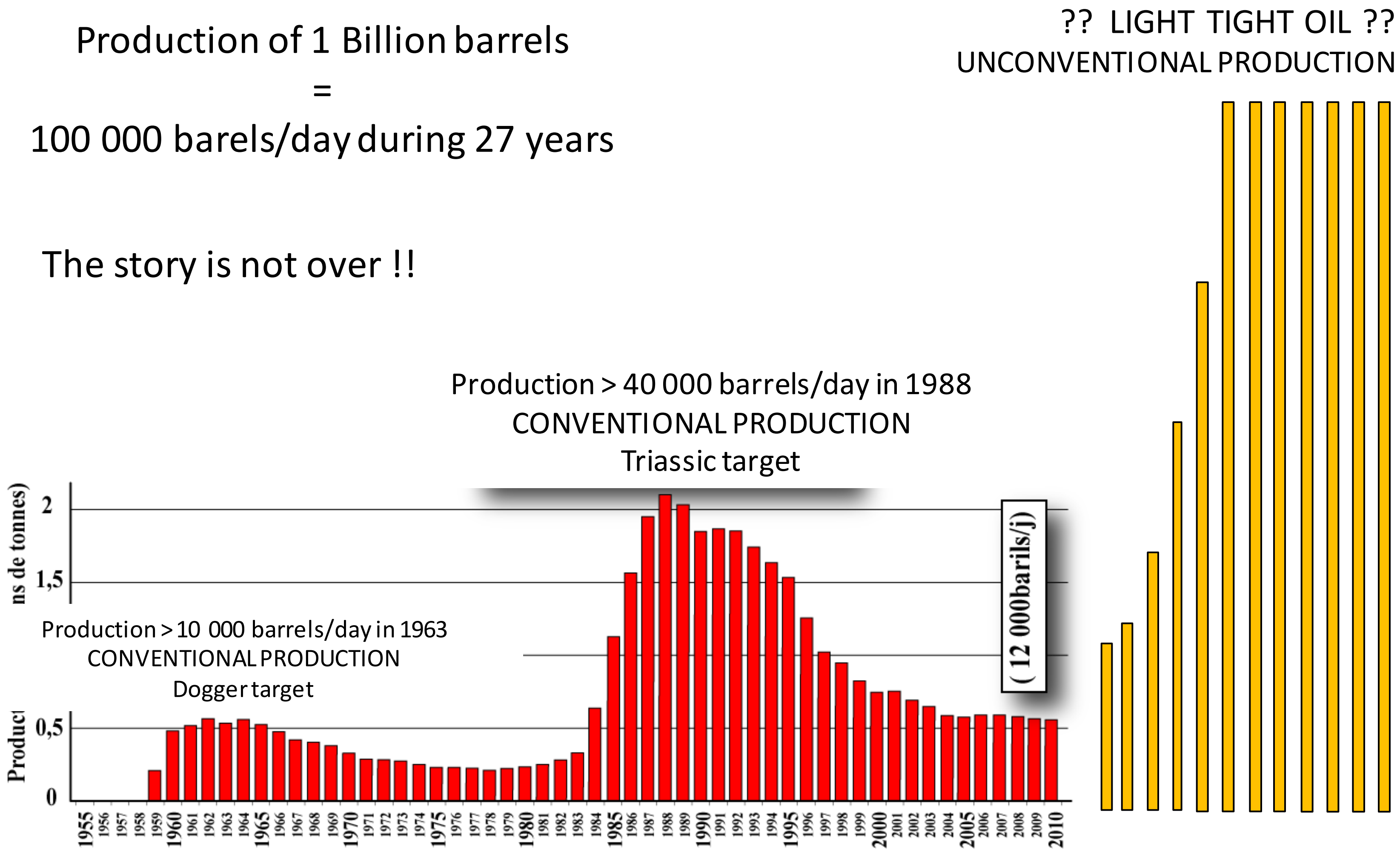
Source : Monticone et al., 2011

Basin modelling

Oil production in the Paris Basin

Production of 1 Billion barrels
=
100 000 barels/day during 27 years

The story is not over !!



Uncertainty

The uncertainty is twofold:

- Will the development project be carried out?
- If so, what will be the outcome?

Will the development project be carried out?

Definitions

- Field already on production or close to start up, proven economy $\rightarrow$ *reserves*
- Field under evaluation $\rightarrow$ *contingent resources*
- exploration $\rightarrow$ *prospective resources*
- PS, probability of success:

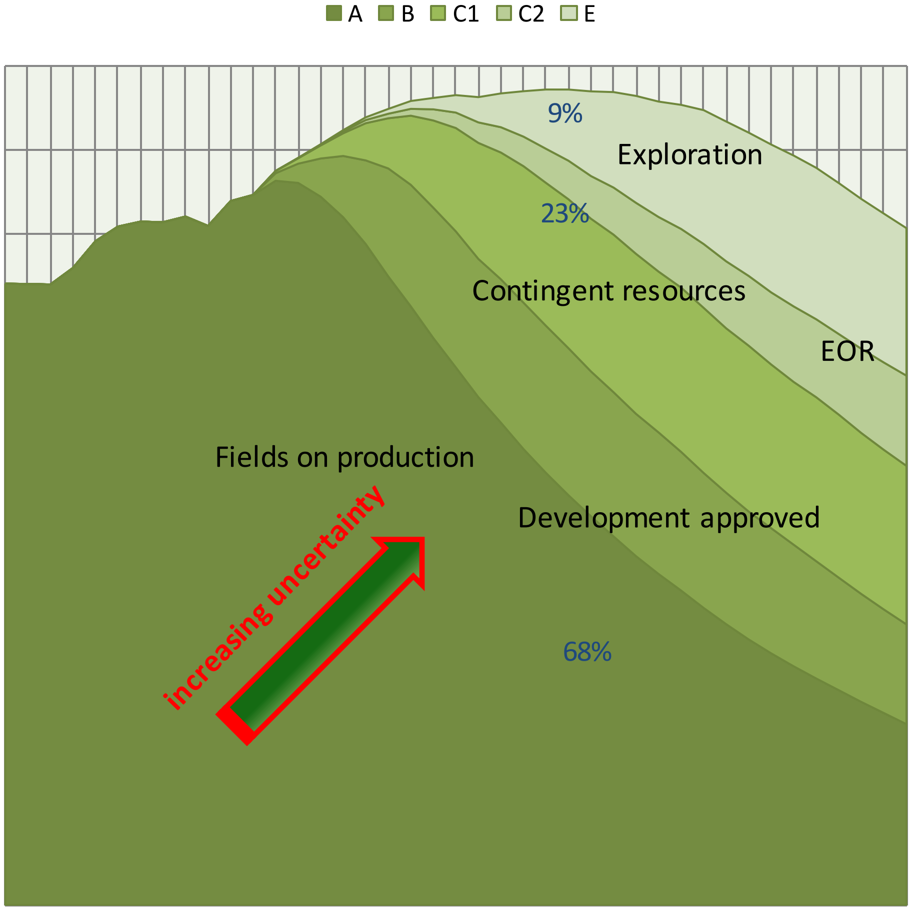
risked resources = technical resources x PS

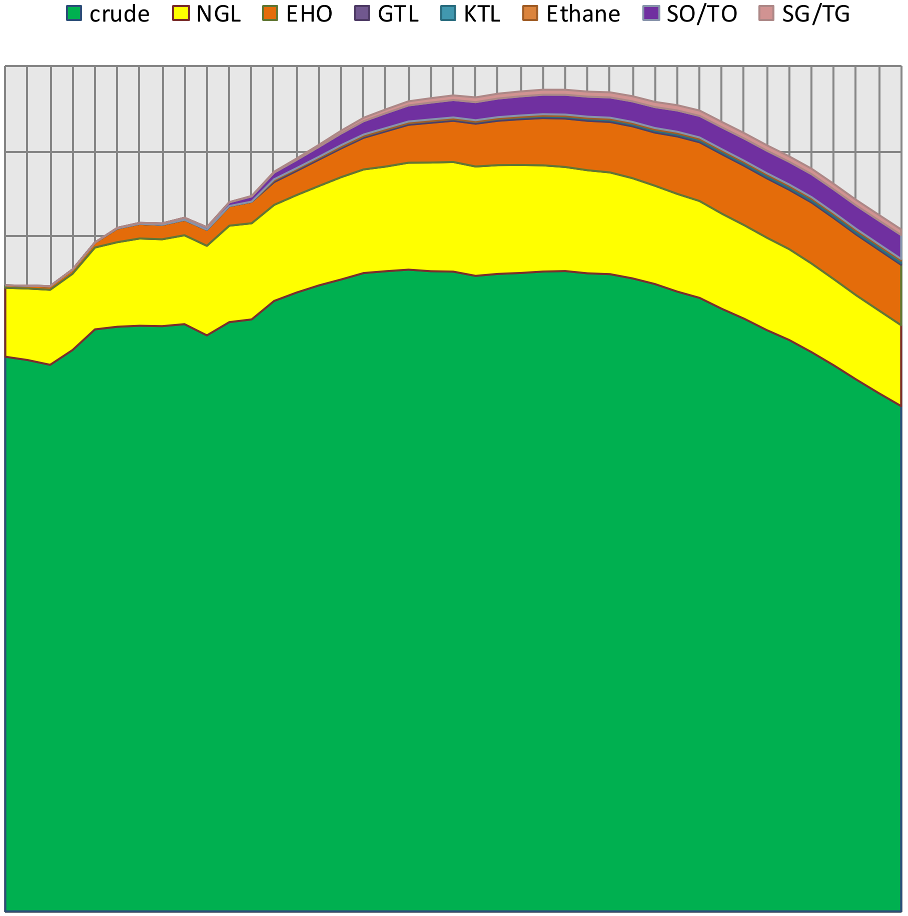
  - Reserves: PS = 100%
  - Contingent resources: PS > 50%
  - Prospective resources: PS between 10% and 50%

What will be the outcome?

- Reserves estimates
  - 1P or P90 or Q10: 90% probability to be exceeded
  - 2P or P50 or Q50: 50% probability to be exceeded
  - 3P or P10 or Q90: 10% probability to be exceeded
- Resources : Mini/Mode/maxi or Low/Best/high
- Proven reserves = 1P
- <u>What is used in the profiles</u>: *2P reserves and risked mode resources*

Prediction of potential



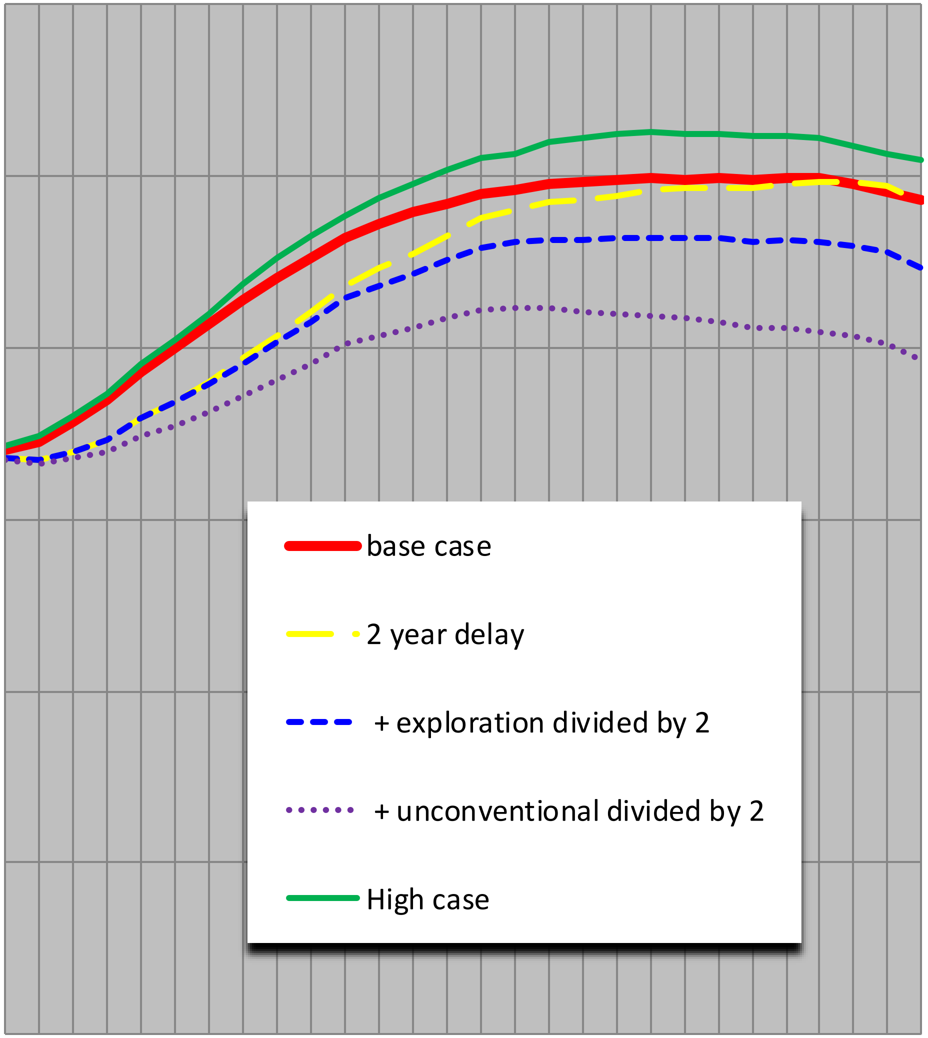


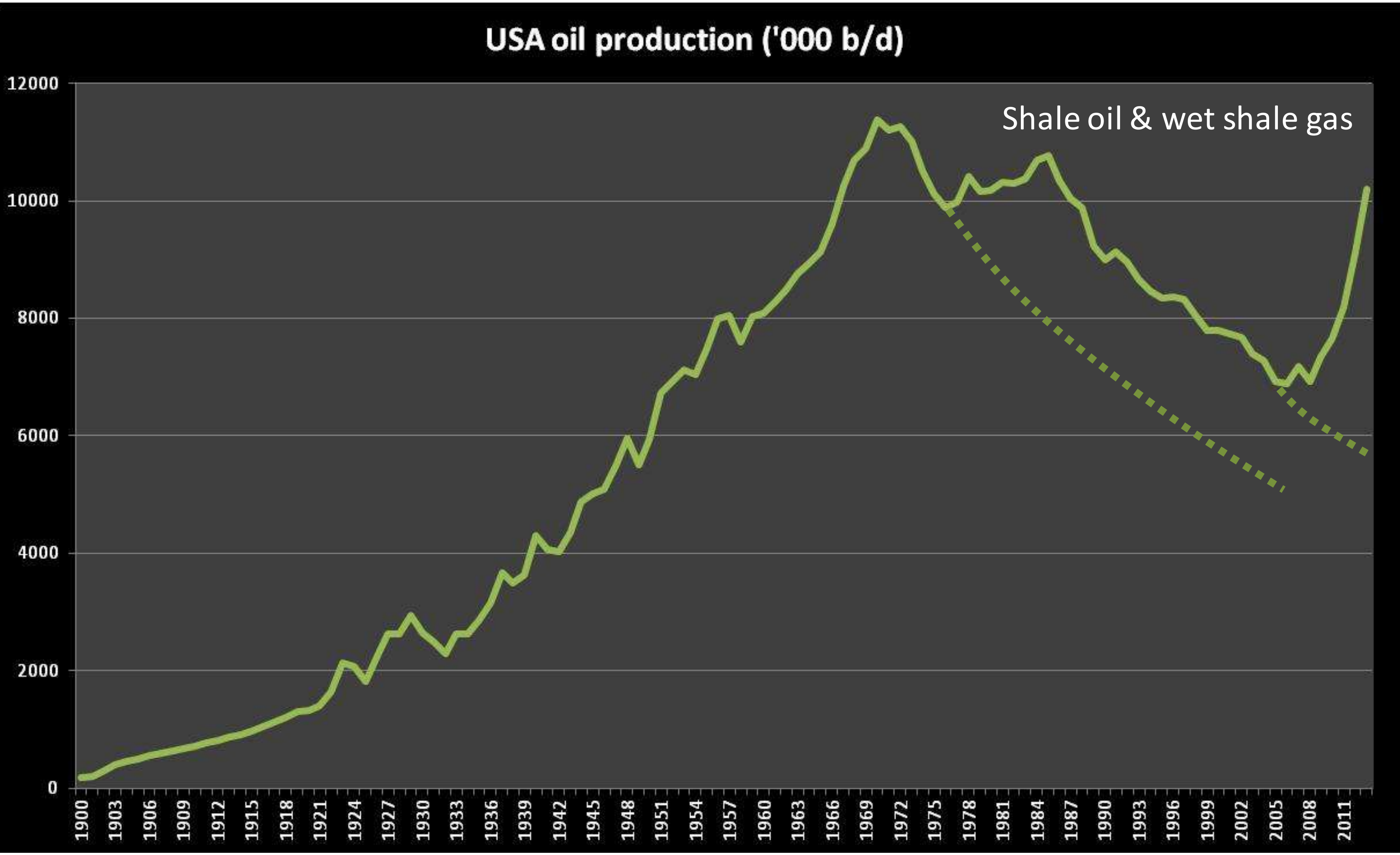
Sensitivity study

<u>Base case</u>: 2P reserves + mode risked resources

<u>Sensitivity cases</u>:

- all projects are delayed by 2 years
- the exploration potential is divided by 2
- the unconventional potential is divided by 2




USA oil production ('000 b/d)
Shale oil & wet shale gas
12000
10000
8000
6000
4000
2000
0
1900
1903
1906
1909
1912
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Shale revolution: a game changer in North America

- After 10 years, shale contributes to 42% of US gas production.
- USA 1st gas producer worldwide.
- USA stopped to import gas and will export LNG soon.
- US Gas price = Europe/3, = Asia/4.5
- Gas replaces coal in power plants → reduction in CO_2 emissions
- Drop in coal price → export to Europe → shut in of modern gas plants → increase in CO_2 emissions
- USA 1st producer of liquid hydrocarbons worldwide, self sufficient within the next decade → impact on oil price.
- USA net exporters of petroleum products → impact on European refineries

Everything you wanted to know about gas…but were afraid to ask

Gas is the cleanest of the fossil fuels

- Coal : $C + O_2 \rightarrow CO_2$
  - 37 g de CO_2 to boil 1 litre of water

- Gaz : $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$
  - 17 g de CO_2 to boil 1 litre of water

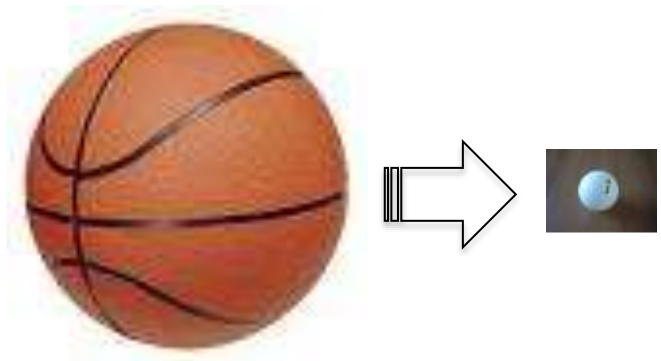
Fuel	Calorific capacity (MJ/kg)	CO2 emissions (t/MWh)
Methane	54	0.4
Oil	38	0.6
Coal	24	0.8
Estonian Oil shales	9	1.1

Transport : gazoduc ou liquéfaction

- ✓ Les 2/3 du gaz utilisé sont vendus dans le pays producteur et acheminés au marché par gazoduc. Le tiers restant est vendu sur le marché international, 70% étant acheminés par gazoduc, le reste sous forme de GNL.
- Donc le transport sous forme liquide concerne environ 10% de la production.
  - *Source : Cedigaz*
- GNL plus économique sur longues distances offshore (> 2000 km). Autre intérêt : plus grand choix de marchés.
- Inconvénient : coût, ressources minimales de 85 bcm (3 tcf).
- ➢ Plus long gazoduc offshore : North Stream, 1224 km sans compression intermédiaire, 220 b au départ en Russie, 100 b à l'arrivée en Allemagne, revêtement interne antifriction, épaisseur décroissante.
- Projet Nabucco : 3900 km entre Turquie et Autriche, 31 bcm/an (1 tcf)

Liquéfaction

Temperature reduced to -161 °C ➔ Volume divided by 600 :



First commercial plant: Arzew (Algérie), 1964, 3 trains of 280 ktpa

Largest train today: Qatargas 4, 7.8 Mtpa (30 x, power of the cooling compressors ~ 8 B747 taking off)

Autres options : CNG & GTL

- CNG : gaz comprimé à 250 b, utilisation dans les transports (NGV)
  - Part actuelle dans les carburants de transport < 1%
  - Part actuelle dans la demande de gaz < 1%
  - Pakistan, Iran, Argentine, Brésil, Inde

- GTL : intéressant si différentiel oil-gas > 13 $/MBTU
  - 1 bcm de gaz (35 bcf) donne 4 Mb d'huile (rendement ~ 0.6)
  - Pearl (QP, Shell), plus grosse usine au monde (140 kbj) comporte 6000 km de tuyaux
  - Pays développant le GTL : Qatar, Afrique du Sud, Nigéria, Malaisie, capacité totale ~ 250 kbj
  - Projets Sasol en Ouzbékistan et aux USA
  - GTL offshore pour gaz acide (Brésil) : CompactGTL (GB).
  - Ressources de gaz associé sans valeur commerciale > 28 tcm selon CompactGTL.

Gas market rigidity

Henry Hub (USA) : < 4 $/MBTU

Japan contracts : ~ 15 $/MBTU

European contracts : 13 $/MBTU

Spot UK ~ 10 $/MBTU