Cement Manufacturing's Impact on Cement Durability in Oil & Gas Wells Applications

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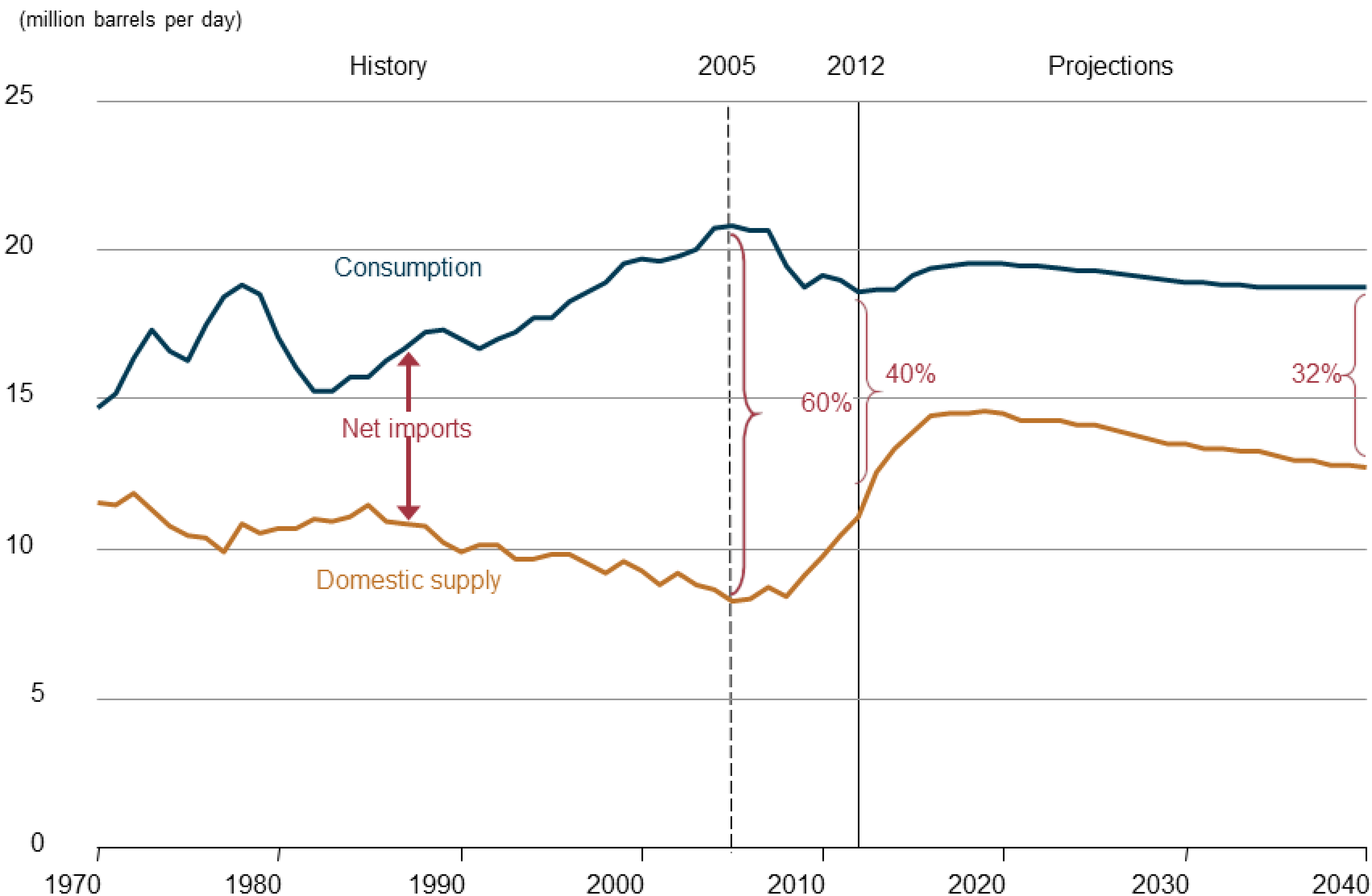
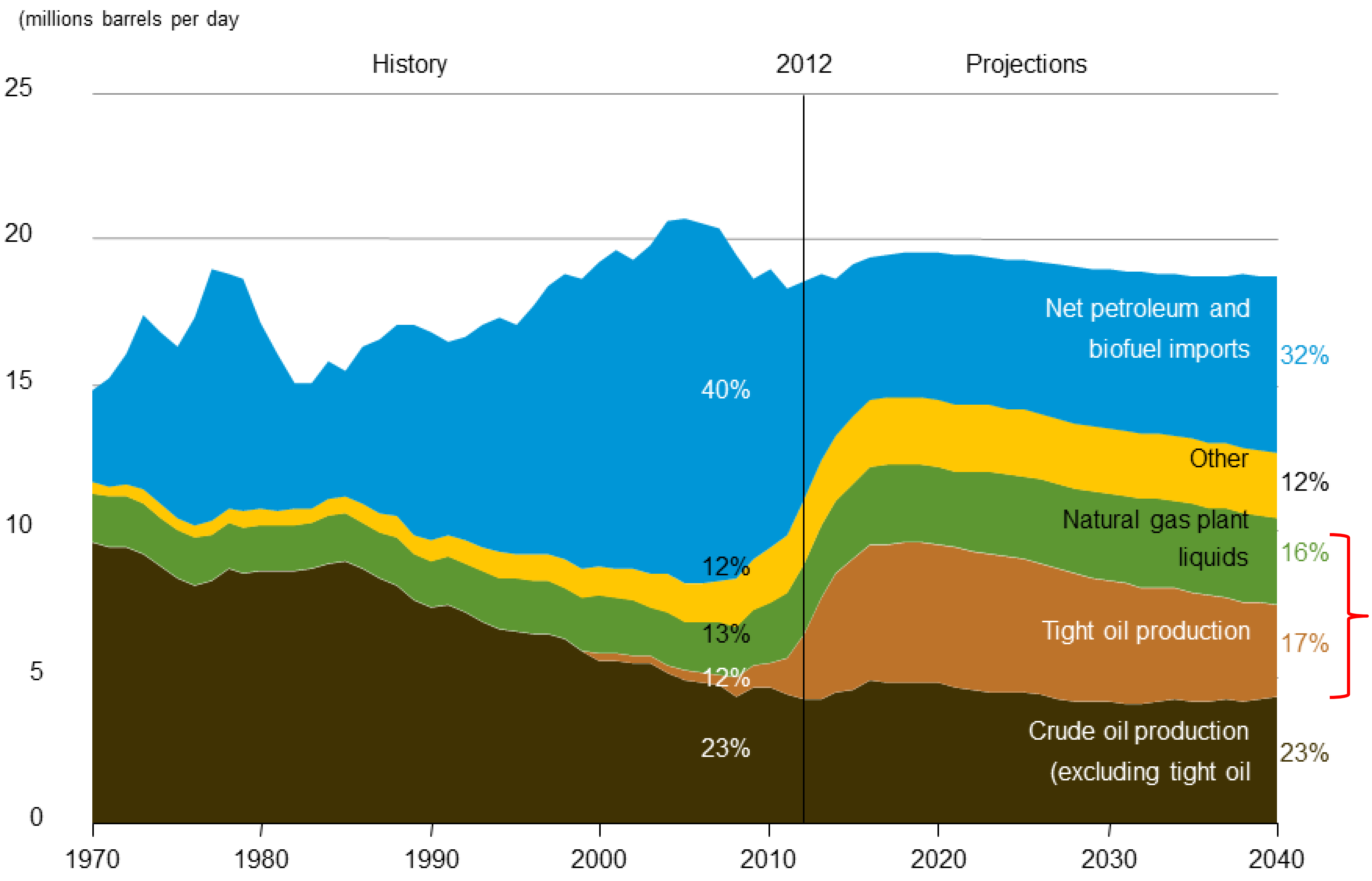
U.S. Oil supply landscape, domestic vs. foreign, is reshaping…..



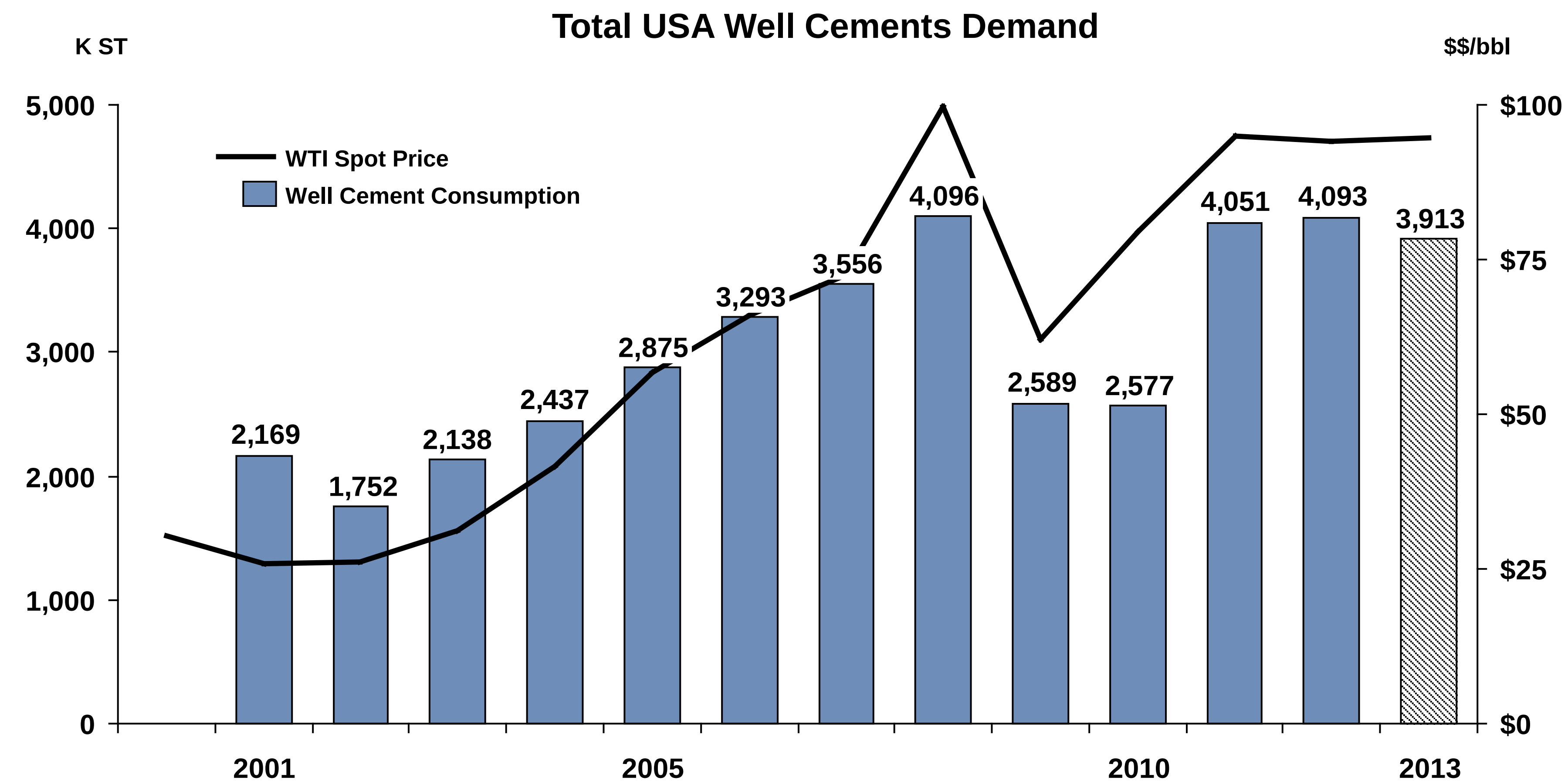
Source: EIA Annual Energy Outlook 2014

… driven mainly by new technologies and processes that have made key shale oil and gas “basins” economically feasible.



Source: EIA Annual Energy Outlook 2014

Heavily impacting demand for oil field services products (e.g. cement).



Oil-Well Share of Total Cement Consumption													
	2%	2%	2%	2%	2%	2%	3%	4%	3%	3%	5%	5%	4%

Source: PCA_Summer Forecast
Historical State and Market Reports

CEMEX – World leader in construction materials

United Arab Emirates Czech Republic Germany Dominican R. Mexico Colombia Panama Finland Costa Rica Ireland Thailand Malaysia France Bangladesh Spain Norway Austria Israel Poland Egypt Puerto Rico UK USA Croatia Nicaragua Hungary Latvia Sweden Switzerland Philippines Argentina

Facts & Figures

Founded in Mexico in 1906

Annual sales ’13 US$15.23 billion, EBITDA ’13 US$2.6 billion

One of the leaders in each of our core businesses:
gray cement, special cements, aggregates, and ready-mix concrete

Presence in more than 50+ countries across the Americas, Europe, Africa, the Middle East, and Asia

Trade relationships with more than 100 nations and one of the world’s top traders of cement and clinker

~43,000 employees worldwide

1) Company annual reports 2013

A Global Leader In Construction Materials[1]

Our world rankings

55 cement plants

3
Cement

1784 RMix plants

1
Concrete

362 Quarries

3
Aggregates

Business Strategy

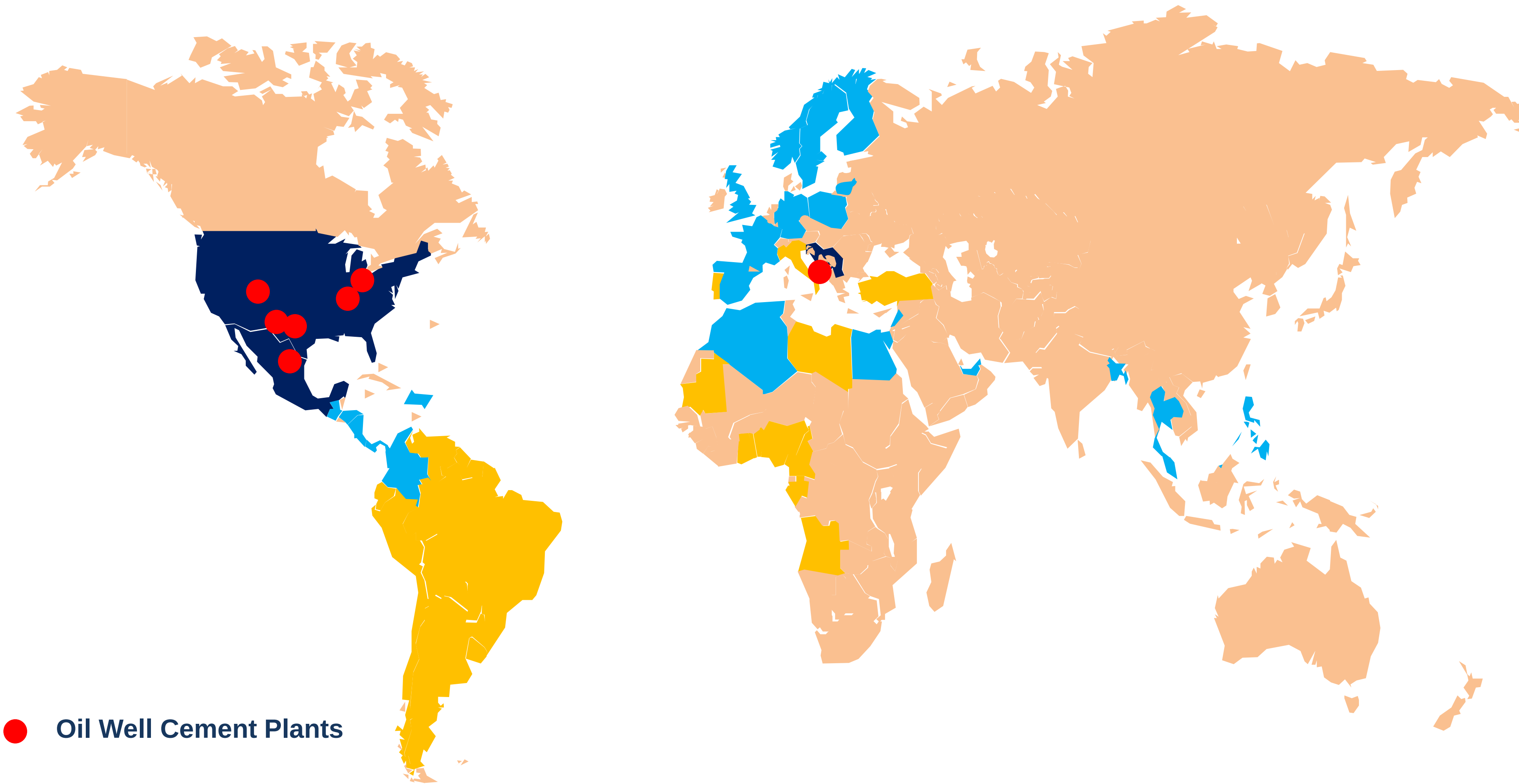
Focus on our core business of cement, oil well cement, ready-mix concrete, and aggregates

Provide our customers with the best value proposition

Maximize our operating efficiency

Foster our sustainable development

CEMEX – Oil Well Cement Service Footprint



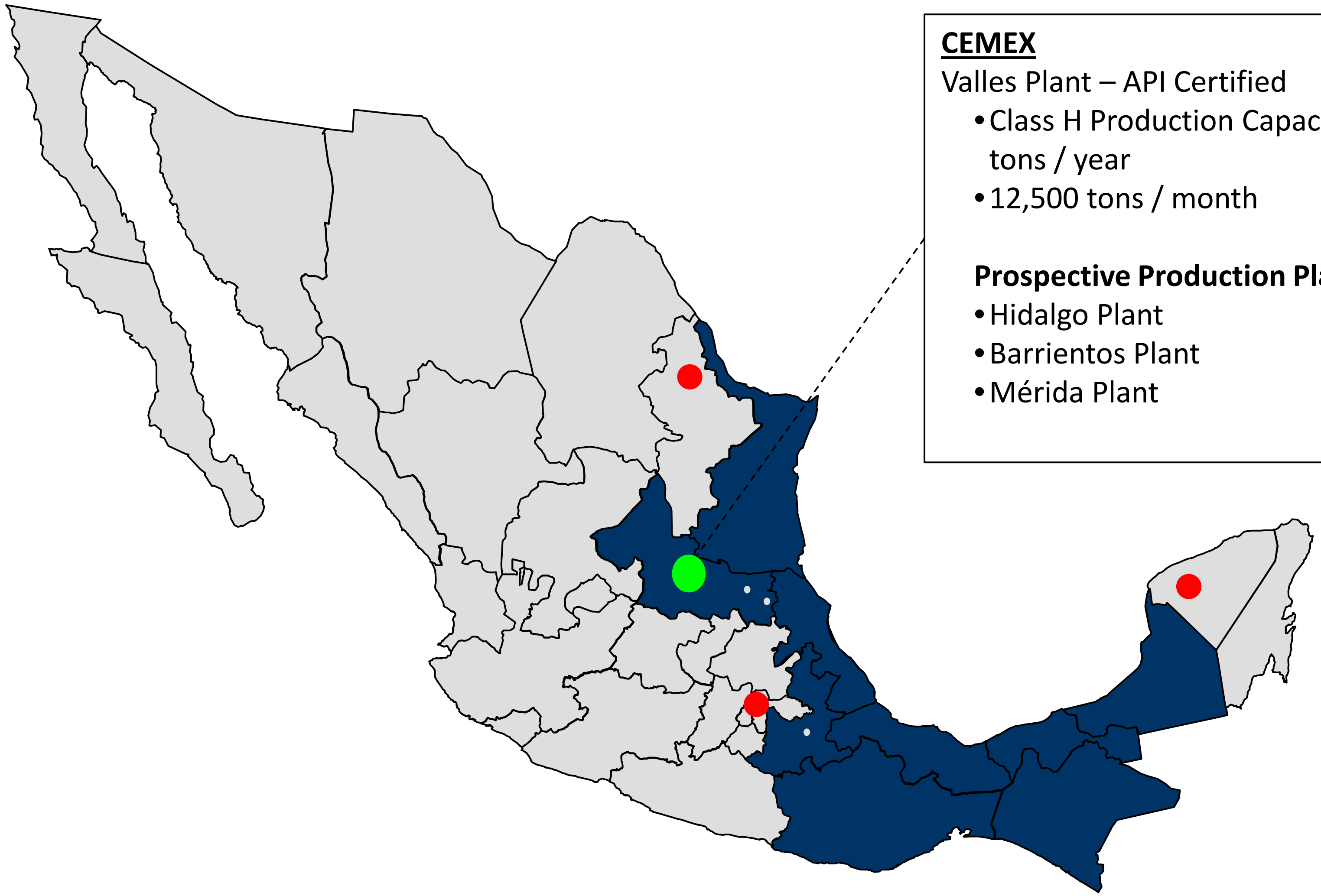
- Oil Well Cement Plants
- CX Oil Well Producing Countries
- CX Countries with Warehouses & Local logistics
- Other Countries were we currently deliver cement

Serving our O&G customers' needs for over 100 years.

CEMEX USA Strategically positioned near major Oil & Gas basins

CEMEX Mexico has a dedicated plan with an extensive logistics' network

Valles Plant Line #1 dedicated to Oil Cement with 2 silos for class H cement, each one with 2,000 tons capacity. The main markets are: Poza Rica, Reynosa and Villahermosa.



CEMEX

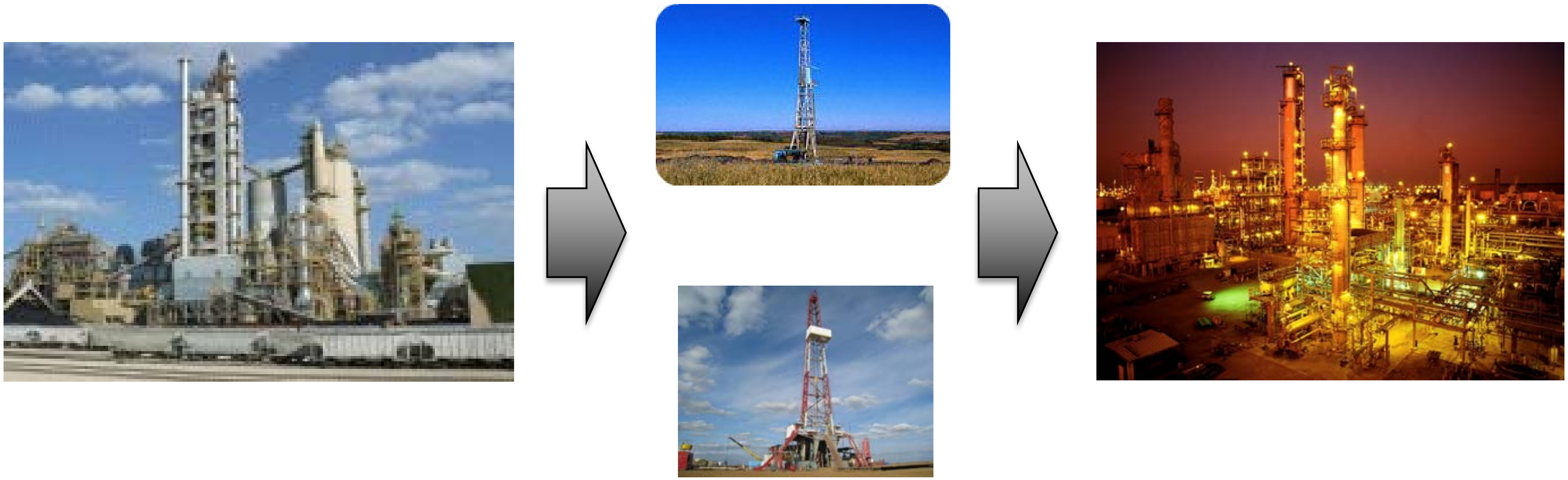
Valles Plant – API Certified

- Class H Production Capacity 150,000 tons / year
- 12,500 tons / month

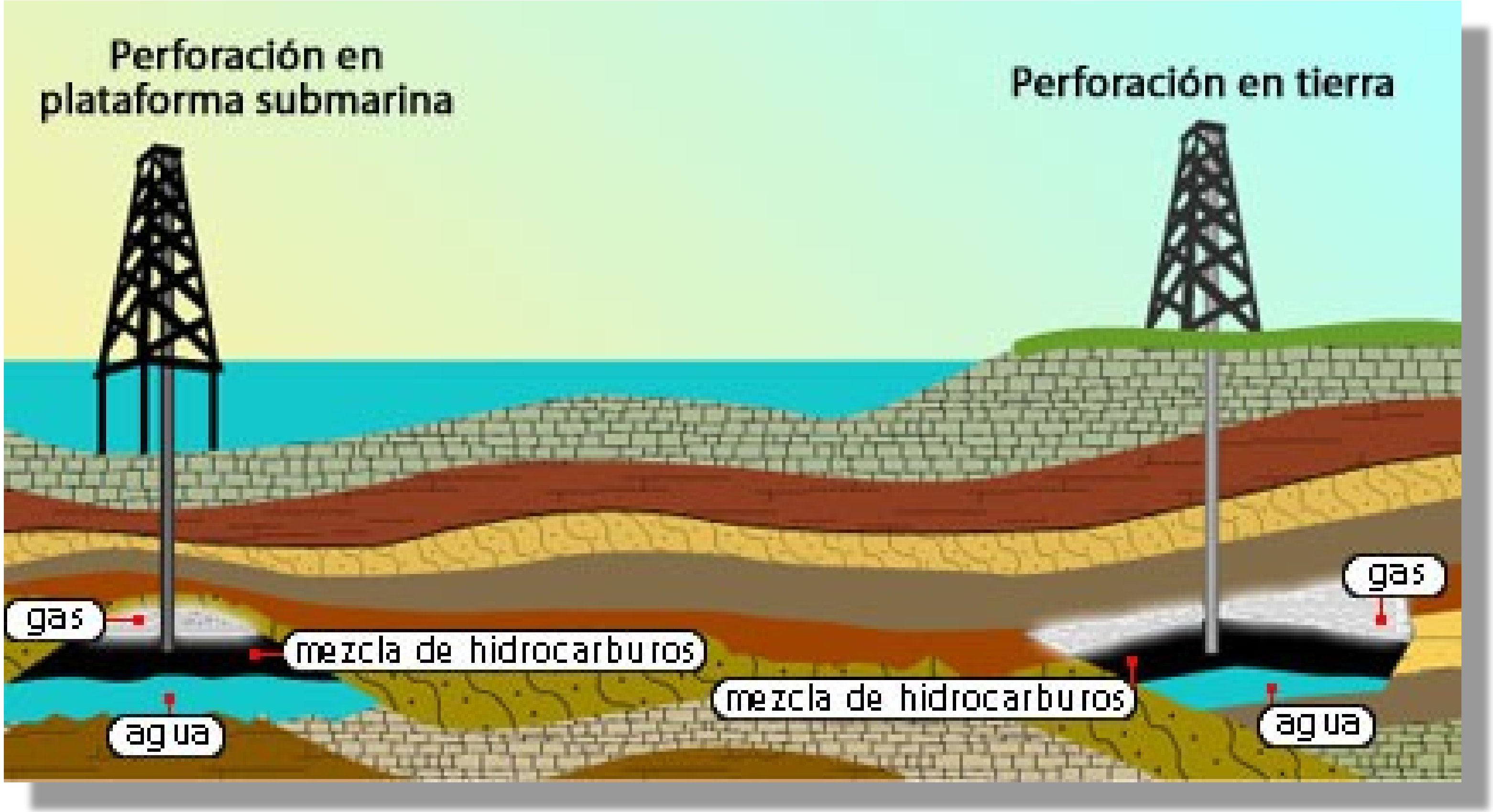
Prospective Production Plants

- Hidalgo Plant
- Barrientos Plant
- Mérida Plant

CEMENT – A MINOR COMPONENT BUT KEY ELEMENT IN EXPLORATION AND PRODUCTION



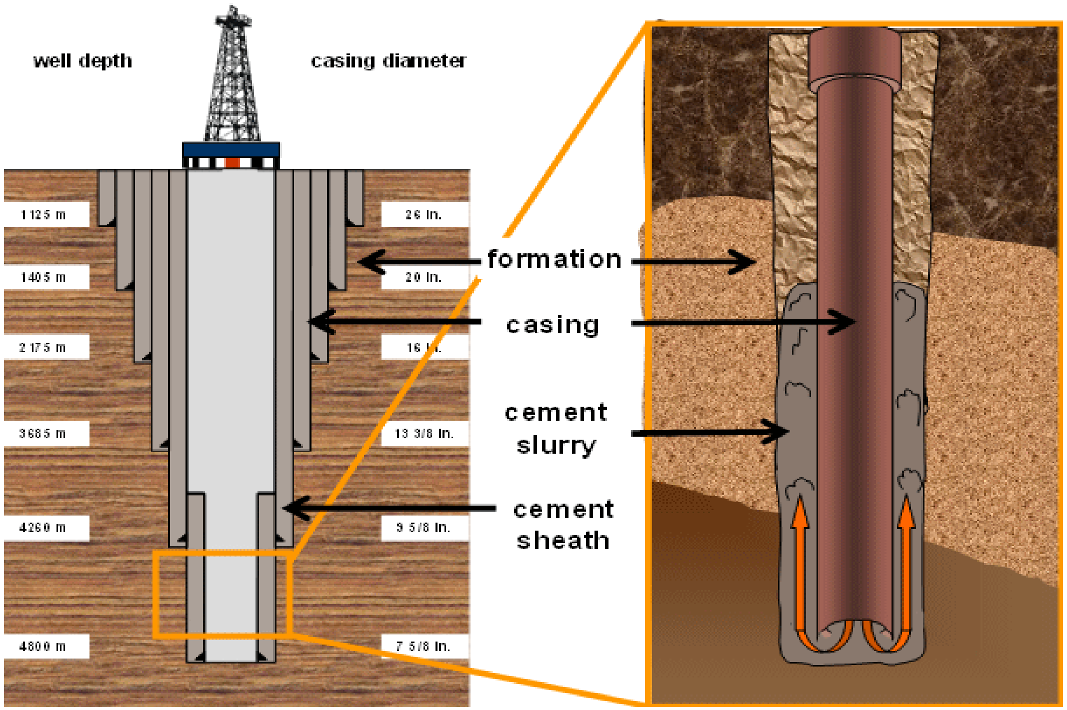
The severe operating conditions of oil wells (with depths of 9000 m [5.6 miles], temperatures of 260°C [500°F] and pressures around 200 MPa) demand cements with very specific chemical and physical characteristics, so its manufacture must be carefully controlled.



Within the operations developed in the oil or gas wells **cementing** is one of the most important, the primary functions of the layer of cement are:

1. To support the vertical and radial loads applied to the casing
2. Isolate porous formations from the producing zone formations
3. Exclude unwanted sub-surface fluids from the producing interval
4. Protect casing from corrosion
5. Resist chemical deterioration of cement
6. Confine abnormal pore pressure
7. To increase the possibility to hit the target

Cementing oil well



According to the conditions of each drilling and its chemical and physical requirements, API (American Petroleum Institute) establishes 8 oil well cement classes from A to H. Its principal difference lies in the moderate or high resistance to the sulphate attack, which determines the depth at which they can be used.

The cements used at greater depths and in more aggresive environments are the class G and H, which have a very similar chemical composition and differ from one another only in the particle size.

American Petroleum Institute

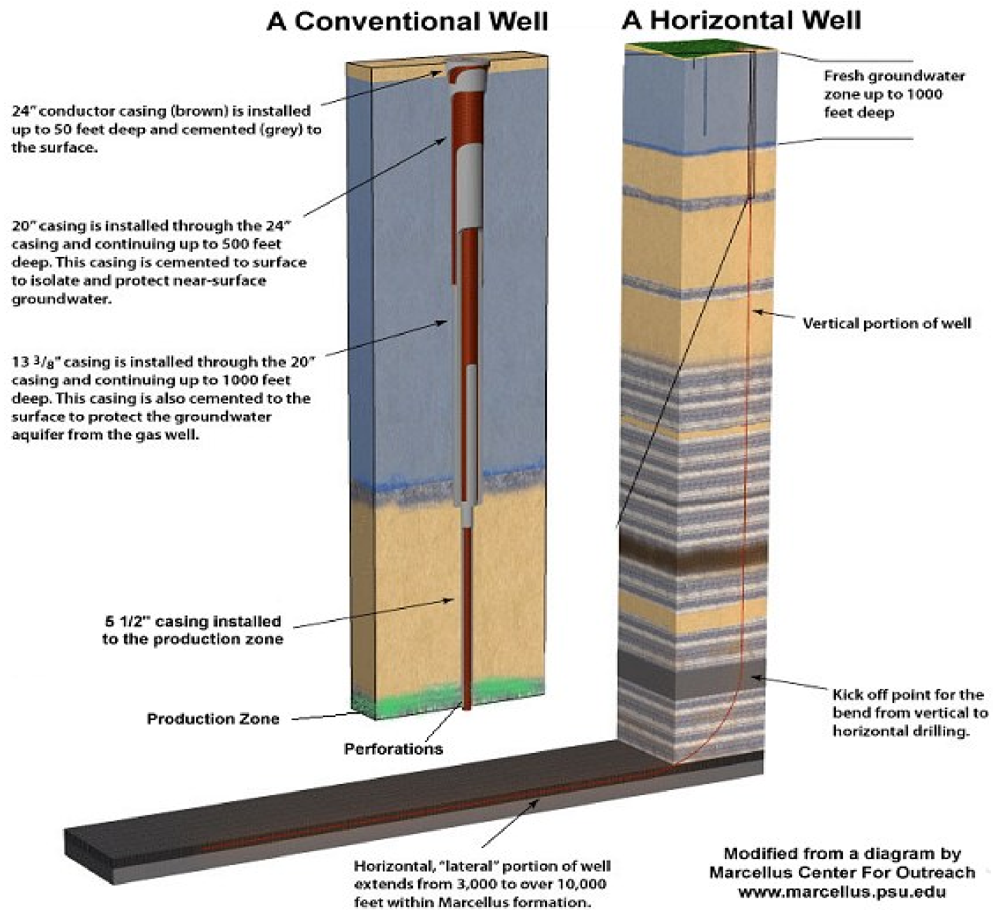
API Cement Classes.

- A. 0–6000 ft used when special properties are not required.
- B. 0–6000 ft used when conditions require moderate to high sulphate resistance
- C. 0–6000 ft used when conditions require high early strength
- D. 6000–10000 ft used under moderately high temperatures and pressures
- E. 10000–14000 ft used under conditions of high temperatures and pressures
- F. 10000–16000 ft used under conditions of extremely high temperatures and pressures
- G. 0–8000 ft can be used with accelerators and retarders to cover a wide range of well depths and temperatures.
- H. 0–8000 ft can be used with accelerators and retarders to cover a wide range of well depths and temperatures.
- J. 12000–16000 ft can be used under conditions of extremely high temperatures and pressures or can be mixed with accelerators and retarders to cover a range of well depth and temperatures.
- API cement grades A, B and C correspond to ASTM type I, II and III.

For placement in the oil well a cement slurry is prepared, it must remain sufficiently plastic or mobile during pumping and once placed must quickly develop enough compressive strength to prevent the union of the fluids used in the formation of the wellbore.

The design of the each slurry is unique, since it depends on the conditions of the oil well and the additives used.

Depending in the drilling conditions such as the depth, temperature, pressure, salinity, etc. various additives are used, including additives for fluid loss, dispersants, retarders, anti-migrating polymers to achieve the complex gas properties required in the cement slurry.



For optimum results in the use of additives is required deep understanding of the action mechanisms, the interaction with cements and compatibiliby between them.

The choice of the additives and the cements is basic for the design of the slurry, its consistency and optimal protection of the well.

Cement parameters:

- Particle size distribution.
- Distribution of silicate and aluminate phases.
- Reactivity of hydrating phases.
- Gypsum/hemihydrates ratio and total sulphate content.
- Free alkali content.
- Chemical nature quantity and specific surface of initial hydration products.

Additives and mechanism of action:

There are 8 general categories of additives.

1. **Accelerators** reduce setting time and increases the rate of compressive strength build up.
2. **Retarders** extend the setting time.
3. **Extenders** lower the density.
4. **Weighting Agents** increase density.
5. **Dispersants** reduce viscosity.
6. **Fluid loss control agents**.
7. **Lost circulation control agents**.
8. **Specialty agents**.

The specifications of the oil well cements are defined by the quality norm API 10A, that states the physical and chemical characteristics of the oil well cements.

Table 1 — Chemical requirements

	Cement class					
	A	B	C	D	G	H
Ordinary grade (O)						
Magnesium oxide (MgO), maximum, percent	6,0	NA[a]	6,0	NA	NA	NA
Sulfur trioxide (SO_3), maximum, percent[b]	3,5	NA	4,5	NA	NA	NA
Loss on ignition, maximum, percent	3,0	NA	3,0	NA	NA	NA
Insoluble residue, maximum, percent	0,75	NA	0,75	NA	NA	NA
Tricalcium aluminate (C_3A), maximum, percent[d]	NR[c]	NA	15	NA	NA	NA
Moderate sulfate-resistant grade (MSR)						
Magnesium oxide (MgO), maximum, percent	NA	6,0	6,0	6,0	6,0	6,0
Sulfur trioxide (SO_3), maximum, percent[b]	NA	3,0	3,5	3,0	3,0	3,0
Loss on ignition, maximum, percent	NA	3,0	3,0	3,0	3,0	3,0
Insoluble residue, maximum, percent	NA	0,75	0,75	0,75	0,75	0,75
Tricalcium silicate (C_3S) maximum, percent[d]	NA	NR	NR	NR	58	58
minimum, percent[d]	NA	NR	NR	NR	48	48
Tricalcium aluminate (C_3A), maximum percent[d]	NA	8	8	8	8	8
Total alkali content, expressed as sodium oxide (Na_2O) equivalent, maximum, percent[e]	NA	NR	NR	NR	0,75	0,75
High sulfate-resistant grade (HSR)						
Magnesium oxide (MgO), maximum, percent	NA	6,0	6,0	6,0	6,0	6,0
Sulfur trioxide (SO_3), maximum, percent[b]	NA	3,0	3,5	3,0	3,0	3,0
Loss on ignition, maximum, percent	NA	3,0	3,0	3,0	3,0	3,0
Insoluble residue, maximum, percent	NA	0,75	0,75	0,75	0,75	0,75
Tricalcium silicate (C_3S) maximum, percent[d]	NA	NR	NR	NR	65	65
minimum, percent[d]	NA	NR	NR	NR	48	48
Tricalcium aluminate (C_3A), maximum, percent[d]	NA	3	3	3	3	3
Tetracalcium aluminoferrite (C_4AF) plus twice the tricalcium aluminate (C_3A), maximum, percent[d]	NA	24	24	24	24	24
Total alkali content expressed as sodium oxide (Na_2O) equivalent, maximum, percent[e]	NA	NR	NR	NR	0,75	0,75

a NA indicates "not applicable".

b When the tricalcium aluminate content (expressed as C_3A) of the cement is 8 % or less, the maximum SO_3 content shall be 3 %, or 3,5 % for class C cement.

c NR indicates "no requirement".

d The expressing of chemical limitations by means of calculated assumed compounds does not necessarily mean that the oxides are actually or entirely present as such compounds. The compounds are calculated according to the ratio of the mass percentages of Al_2O_3 to Fe_2O_3, where w is the percentage mass fraction of the compound indicated in the subscript.

— When $w_{Al_2O_3}/w_{Fe_2O_3}$ is greater than 0,64, the compounds shall be calculated as follows:

$C_3A = 2{,}65 w_{Al_2O_3} - 1{,}69 w_{Fe_2O_3}$

$C_3S = 4{,}07 w_{CaO} - 7{,}60 w_{SiO_2} - 6{,}72 w_{Al_2O_3} - 1{,}43 w_{Fe_2O_3} - 2{,}85 w_{SO_3}$

$C_4AF = 3{,}04 w_{Fe_2O_3}$

— When $w_{Al_2O_3}/w_{Fe_2O_3}$ is 0,64 or less, the C_3A content is zero.

— The C_3S and C_4AF shall be calculated as follows:

$C_3S = 4{,}07 w_{CaO} - 7{,}60 w_{SiO_2} - 4{,}48 w_{Al_2O_3} - 2{,}86 w_{Fe_2O_3} - 2{,}85 w_{SO_3}$

$C_4AF = 3{,}04 w_{Fe_2O_3}$

e The sodium oxide equivalent, expressed as Na_2O equivalent, shall be calculated by the formula:

Na_2O equivalent is equal to $0{,}658 w_{K_2O} + w_{Na_2O}$

Table 2 — Summary of physical and performance requirements

Well cement class				A	B	C	D	G	H
Mix water, % mass fraction of cement (Table 5)				46	46	56	38	44	38
Fineness tests (alternative methods) (Clause 6)									
Turbidimeter (specific surface, minimum, m^2/kg)				150	160	220	NR[a]	NR	NR
Air permeability (specific surface, minimum, m^2/kg)				280	280	400	NR	NR	NR
Free-fluid content, maximum, percent (Clause 8)				NR	NR	NR	NR	5,9	5,9
Compressive strength test (8 h curing time)	Schedule number Table 6	Final curing temperature °C (°F)	Curing pressure MPa (psi)	Minimum compressive strength MPa (psi)					
(Clause 9)	NA[b]	38 (100)	atm.	1,7 (250)	1,4 (200)	2,1 (300)	NR	2,1 (300)	2,1 (300)
(Clause 9)	NA	60 (140)	atm.	NR	NR	NR	NR	10,3 (1 500)	10,3 (1 500)
(Clause 9)	6S	110 (230)	20,7 (3 000)	NR	NR	NR	3,4 (500)	NR	NR
Compressive strength test (24 h curing time)	Schedule number (Table 6)	Final curing temperature °C (°F)	Curing pressure MPa (psi)	Minimum compressive strength MPa (psi)					
(Clause 9)	NA	38 (100)	atm.	12,4 (1 800)	10,3 (1 500)	13,8 (2 000)	NR	NR	NR
(Clause 9)	4S	77 (170)	20,7 (3 000)	NR	NR	NR	6,9 (1 000)	NR	NR
(Clause 9)	6S	110 (230)	20,7 (3 000)	NR	NR	NR	13,8 (2 000)	NR	NR
Thickening-time test	Specification test schedule number Tables 9 through 11	Maximum consistency (15 min to 30 min stirring period) B_c[c]		Thickening time (minimum/maximum) min					
(Clause 10)	4	30		90[d]	90[d]	90[d]	90[d]	NR	NR
(Clause 10)	5	30		NR	NR	NR	NR	90[d]	90[d]
(Clause 10)	5	30		NR	NR	NR	NR	120[e]	120[e]
(Clause 10)	6	30		NR	NR	NR	100[d]	NR	NR

a NR indicates "no requirement".

b NA indicates "not applicable".

c Bearden units of consistency, B_c, obtained on a pressurized consistometer as defined in Clause 10 and calibrated in accordance with the same clause.

d Minimum thickening time.

e Maximum thickening time.

Factors affecting the performance of the cements in oil wells

Temperature – An increase in the temperature accelerates the setting time, strength and proper flow of the cement slurry, the increment in the temperature is related to the depth of drilling, when deeper the drilling the temperature is higher, and the hydrating process of the cement also contributes to raise the temperature.

Pressure - The increase in the pressure affects the pumpable time and speeds the setting time, this effect being less than the increase in the temperature.

Compatibility with additives – Succesful selection of the additives is crucial to that under the conditions of temperature and pressure the mixture retains its rheological properties and compressive strength, thereby preventing abnormal behavior that hinders the cementing process.

The slurry strength depends on many factors, the cement must be sufficiently resistant to keep the insulation of the well and withstand well drilling and fracturing processes.

Long-term Durability of the cemented wall

The insulation layer of cement is exposed to multiple environments, being these excessively aggresive.

The cementing layer is in contact with flowing water, soil with diverse geological formations and with chemical compositions that interact with the cement components, resulting in the most aggressive deterioration cases of the insulating layer.

One of the most frequent attacks of the cemented layer is due to the presence of high concentrations of sulfate ions in the water currents and in the several layers of the drilled material, both in contact with the well.

For an adequate protection it is of paramount importance a proper selection of the cement and the additives to use.

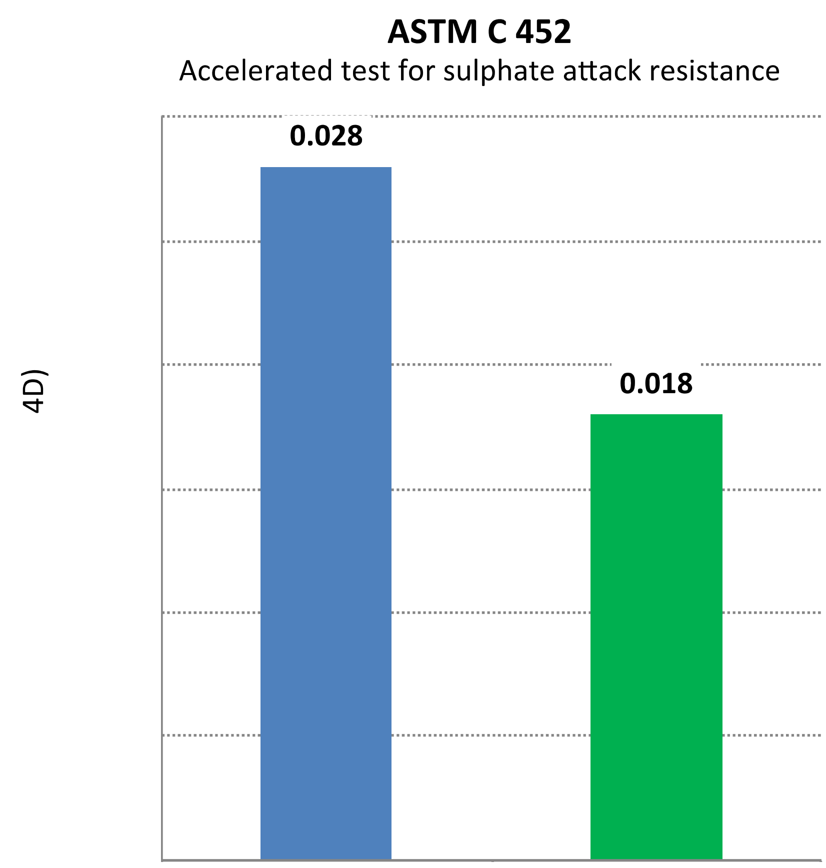
HSR cement is specified by the API for these applications.

The new trends in the oil well cements is the use of cementitious materials to improve the long term durability, the blast furnace slag and fly ash are examples ot this type or materials that provide the cement additional characteristics improving the waterproof characteristis of the cemented layers and contributing to additional chemical resistance and mechanical development after its reaction with some of the hydration products of the cements.

At **Cemex** additional to the use of cementitious materials the use of Nanotechnology is also studied to improve the resistance of the cements to chemical aggresive agents in the environment to which the wells are exposed.

An example of the level of improvement of the chemical resistance of the cement is determined with the accelerated test stated by the american norm ASTM C 452 refering to the exposure of sulphate attack.

Application of nanotechnology oil well cement to increase its durability
(evaluation using the accelerated method for the expansion due to sulphate attack, with a maximum limit of 0.04% at 14D)



For the oil well cement production, the control of the process and the cement characteristics is crucial, at CEMEX we have the highest standards for this procedures.

- Our production process is certified by API
- Our quality management system is certified under the norm 9001 by AENOR
- Our environmental management system is certified under the norm ISO 14001
- Our laboratories are certified by CTL (Certified Testing Laboratories) and EMA (Mexican Accreditacion Entity)

We also have the R&D and service laboratories in Biel-Switzerland, Tampa-USA and Monterrey-Mexico.

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American Petroleum Institute

AENOR

AENOR
Empresa Registrada
UNE-EN ISO 9001

CEMEX'S GLOBAL R&D LABORATORIES

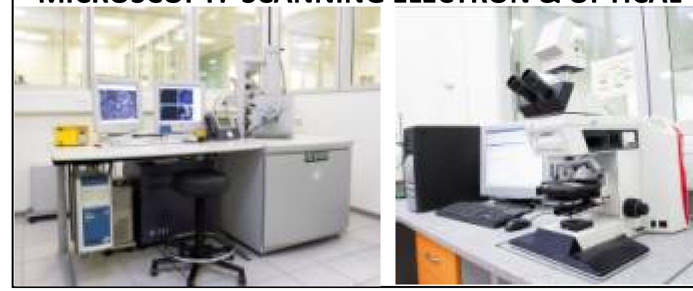
CRG Lab Switzerland
Central Lab México
CTCC lab México
CL Tampa

Facilities designed support the following CEMEX businesses:

a) Cement
b) Ready-Mix
c) Aggregates
d) Admixtures

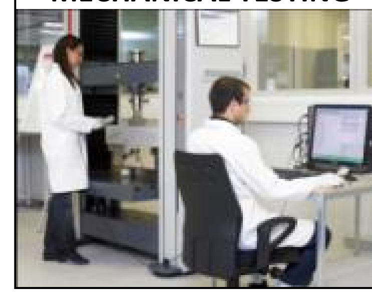
CONCRETE BATCHING & TESTING

MICROSCOPY: SCANNING ELECTRON & OPTICAL



ORGANIC & INORGANIC ANALYTICS

MECHANICAL TESTING



AGGREGATES: Preparation & Testing Facilities

MATERIALS & POWDER CHARACTERIZATION

Cement Manufacturing's Impact on Cement Durability in Oil & Gas Wells Applications