Overview of Petroleum Recovery Methods

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Innovative Applications For Stranded Barrels of Oil

Conference

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Society of Petroleum Engineers

Presentation is based on:

- Pápay J.:2003. Development of Petroleum Reservoirs -Theory and Practice. Hungary. Akadémiai Kiadó. Pp.(1-940). www.akademiaikiado.hu

- Pápay J.:2013. Exploitation of Unconventional Petroleum Accumulations -Theory and Practice. Hungary. Akadémiai Kiadó.Pp(1-361). www.akademiaikiado.hu

- Pápay J.:2015. Exploitation of Tight Oil Plays. (Manuscript-under plublication).

- IEA (International Energy Agency) Data

- EIA-USA (Energy Information Administration) Data

Content

- Classification of petroleum from apects of recovery
- Recovery methods of conventional petroleum
- Recovery methods of unconventional petroleum
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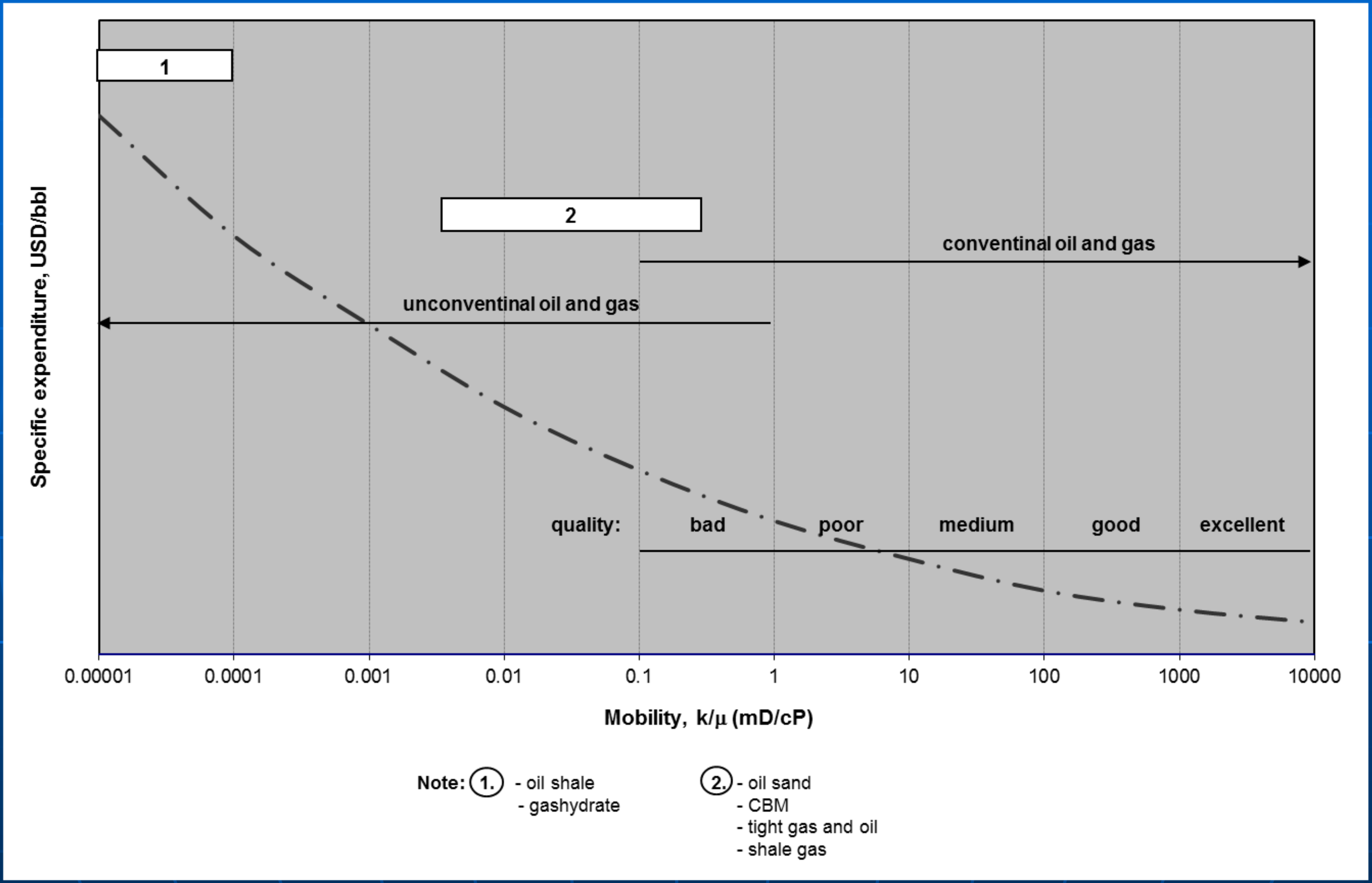
- Predicted US production
- Conclusions



Relation of mobility and cost

Pápay J.-2008-14

Figure 1

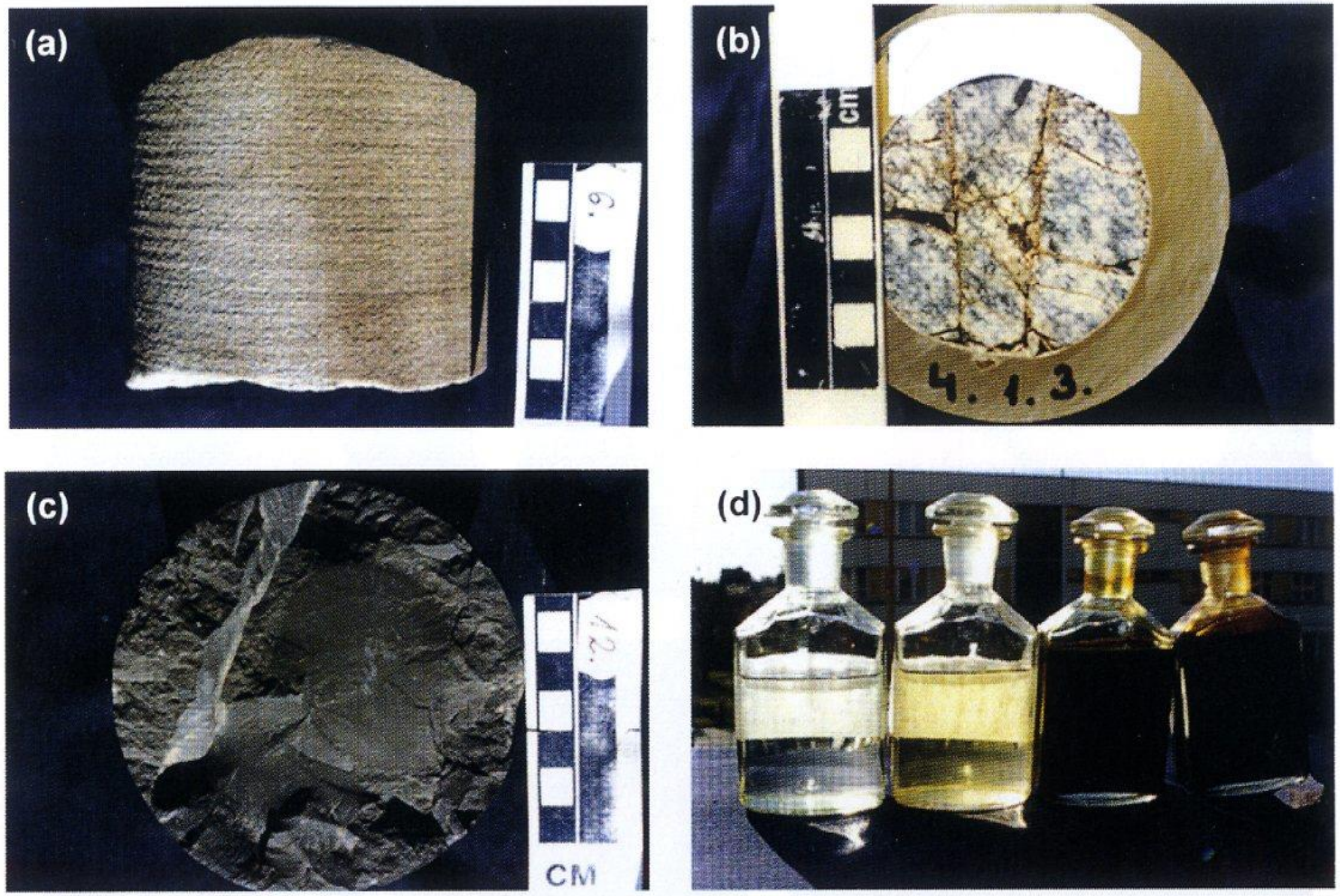


Figure 1.2. Conventional reservoir rocks and fluids

Figure 1.3. Unconventional reservoir rocks and fluids

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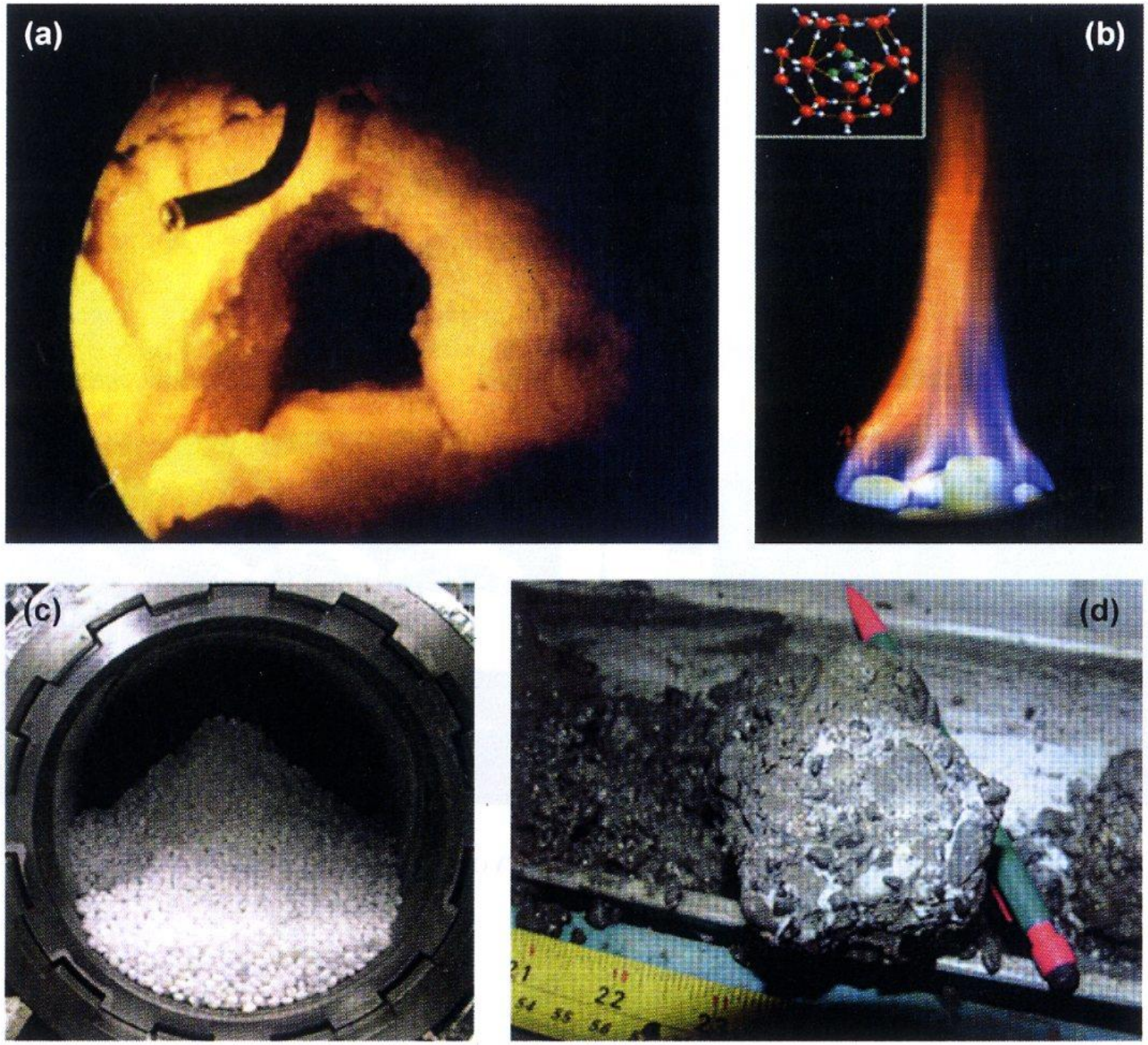

Figure 1.4. Unconventional gas: Hydrate

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Comparition of conventional and unconventional resources
- driving mechanisms-

No	Parameters	Convention.		Unconventional						
				oil			gas			
		oil	gas	oil sand	oil shale	tight light oil	CBM	tight gas sand	shale gas	hydrate
1	permeability k(p)	- ?	- ?	- ?	+?	++	++	++	++	-
2	viscosity	+	-	++	+	+?	-	-	-	++ (-)
3	mobility	+	+?	++	++	++	++	++	++	++
4	gravity (buoyancy)	++	++	- ? (+)	- (+?)	-? (+?)	+* (+)**	- (-?)	- (-?)	- (++)
5	relative perm. (multiphase)	++	++	+? (++)	-? (++)	+? +	- (+)	- (+?)	- (+?)	- (++)
6	capillarity	+	+	+?	-? (+)	+? (+)	- (+?)	++ (++)	++ (++)	- (+)
7	rock compres.	-	-	-	- (+)	+? +	-? (+)	+ (+)	+ (+)	- (-)
8	turbulence flow	-	+?	-	no flow (+?)	+ +?	+? (+?)	+ (+)	+ (+)	no flow (-?)
9	Darcy flow	+	+	+? +	- +	+? +	+? + -	- + -	-? + -	- +
10	hydrodynam	+	+	+?	-?	+?	+	-	-	- (-?)
11	material bal. equation	+	+	_ (-)	_ (-)	- (-)	+ (+)	_ (-)	_ (-)	_ (-)
12	adsorption	-	-	-	-	-	++	-	+	-
	drainage area	L	LL	SS S	SSSS SS	SSSS SS	S L	SS S	SSS SS	SSSS SS

Note : * : original state; ** : improved state; **-** : not; **+**: yes; **-?**: probably not; **+?**: probably yes; **L**: large; **S**: small

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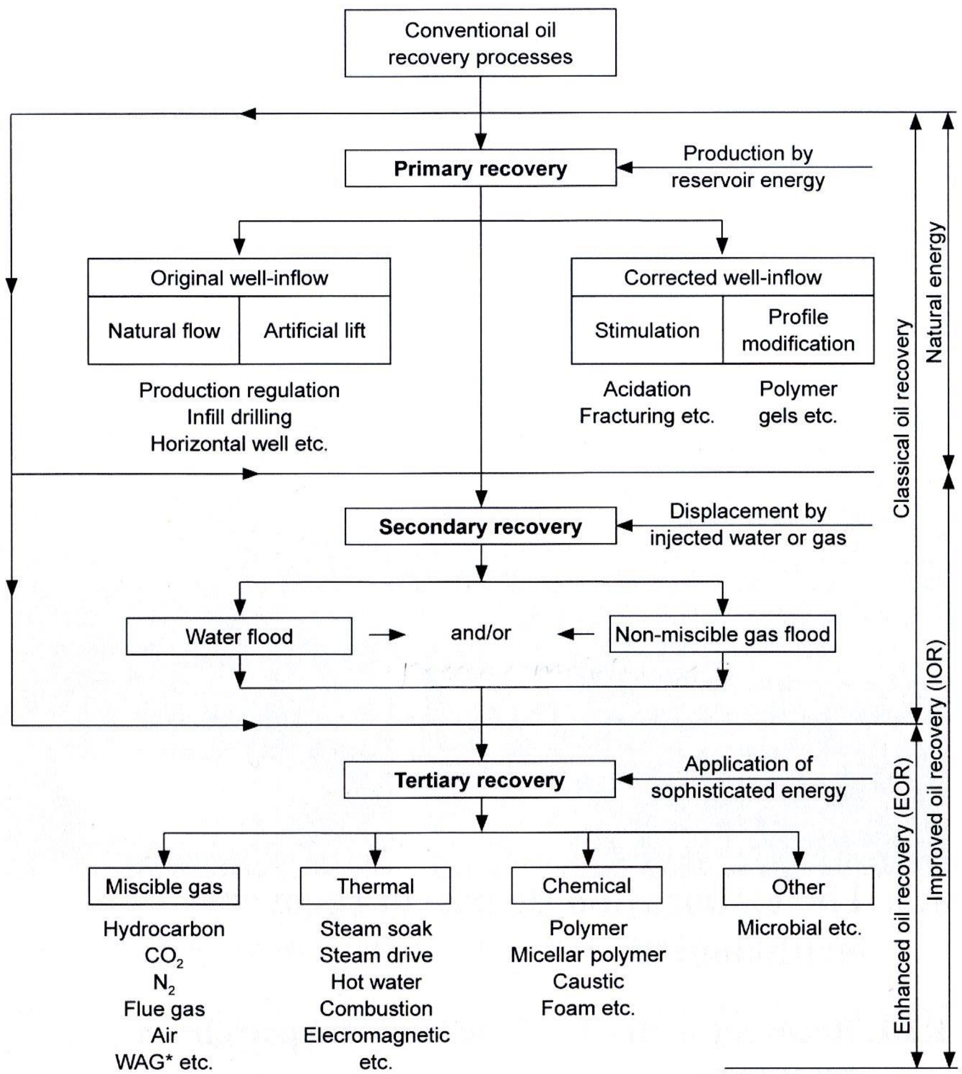

Figure 1.5. Classification of conventional oil recovery processes
(Source: Pápay J. 2003)

Pápay J.-1997-2003

Table 1.3. Screening of conventional oil recovery methods
(Source: Pápay J. 2005)

Recovery method	Type of rock	S_0 [–]	K [mD]	Depth H [ft]	Depth Pr [bar]	Depth Tr [°F]	Oil viscosity [cP]
Natural depletion (primary)							
Using reservoir energy	NC	> 0.4–0.5	> 0.1–1	NC	NC	NC	< 300 (< 10)
Pressure maintenance (secondary)							
Pressure maintenance with injection of non-miscible fluids	NC	> 0.5–0.6 (0.7–0.8)	> 0.1–1 (> 10)	NC	NC	NC	< 300 (< 10)
Enhanced oil recovery (tertiary – EOR)							
Gas miscible flooding							
First contact (C_3-C_4)	(NC)***	> 0.3 (0.7–0.8) [0.8]	> 0.1–1 (> 10)	(NC)	>100	(NC)	< 5 (< 0.5) [0.2]
Multiple contact condensation (C_1-C_2-C_3-C_4)	NC****	> 0.3 (0.7–0.8) [0.75]	> 0.1–1 (> 10)	(NC)	>150	(NC)	< 5 (< 0.5) [0.5]
Multiple contact vaporization (CO_2)	NC	> 0.3 (0.7–0.8) [0.55]	> 0.1–1 (> 10)	(NC)	>180	(NC)	< 10 (< 1) [1.5]
Multiple contact vaporization (C_1, N_2, flue gas)	NC	> 0.3 (0.7–0.8) [0.75]	> 0.1–1 (> 10)	(NC)	>300	(NC)	< 5 (< 0.5) [0.2]
Thermal flooding							
Steam flooding**	High-porosity sand, sandstone	> 0.4 (0.7–0.8) [0.72]	> 200 (> 1000) [2540]	< 4500 (400–4500) [1500]		NC	< 200 000 > 150 (100–10 000) [4700]
In situ combustion**	High-porosity sand, sandstone	> 0.5 (0.7–0.8) [0.66]	> 200 (> 500)	< 11 500 [3500]		> 100 [135]	< 1000 (10–1000) [1200]
Chemical flooding							
Polymer	Sandstone	> 0.5 [0.80]	> 20 [800]	(NC)	(NC)	< 200 [123]	< 150 > 10 (1*–150) [85]
Micellar polymer	Sandstone	> 0.35 [0.53]	> 20 [450]	(NC)	(NC)	< 175 [95]	< 35 [6]
Caustic	Sandstone	> 0.35 [0.53]	> 20 [450]	(NC)	(NC)	< 200	< 200 [15.5]

Notes: ( ) favorable parameters
[ ] average at present application
* if the target is "only" to make the reservoir homogenous
** minimum reservoir thickness for steam > 20 ft, for combustion > 10 ft
*** not very critical
**** not critical

Pápay J. 2005-2013

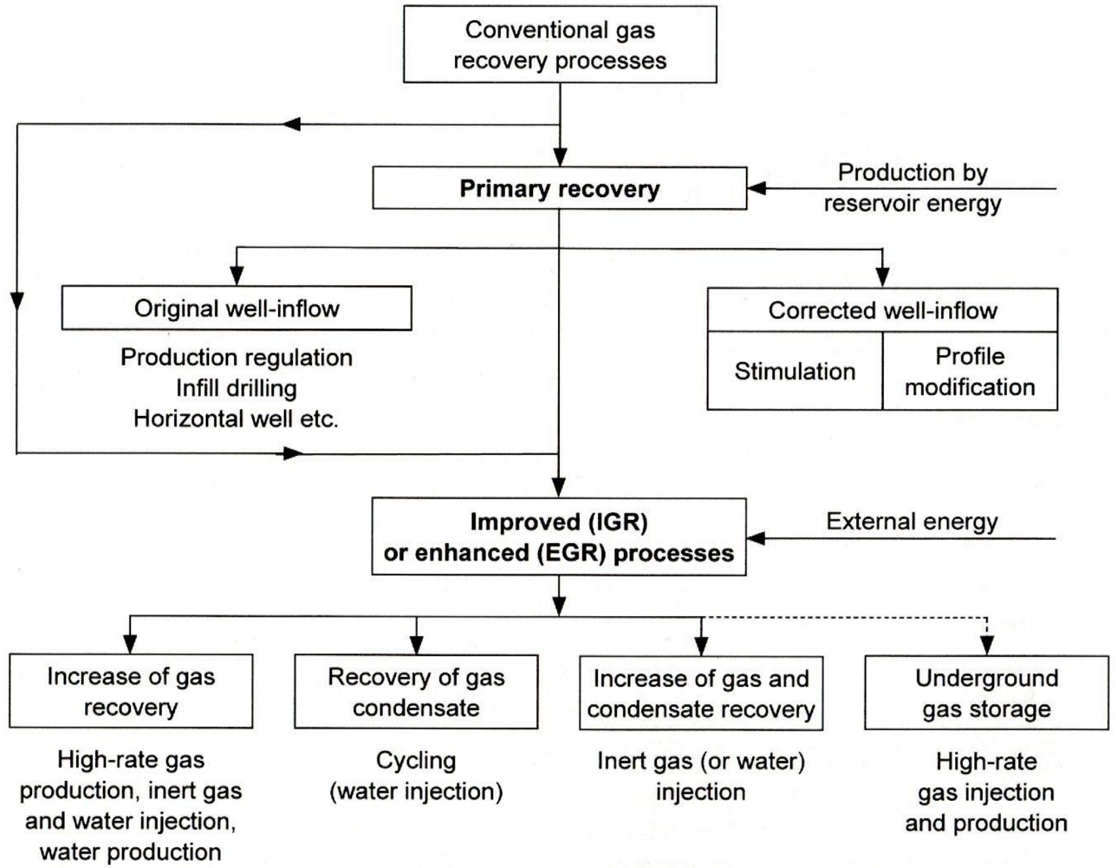

Figure 1.6. Classification of conventional gas recovery processes
(Source: Pápay J. 2003)

Pápay J.-1997-2003

Screening of IGR/EGR

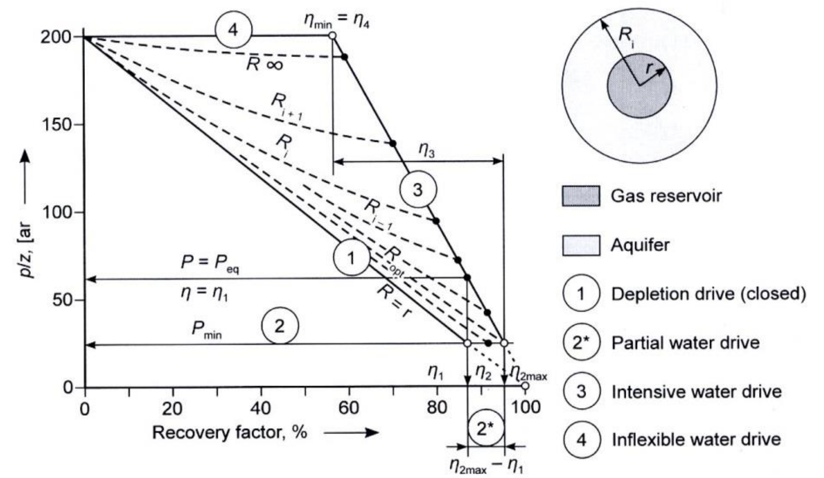

Figure 1.7a. Relation of reservoir pressure and end-point recovery factor for gas reservoir (Source: Pápay J. 2003)

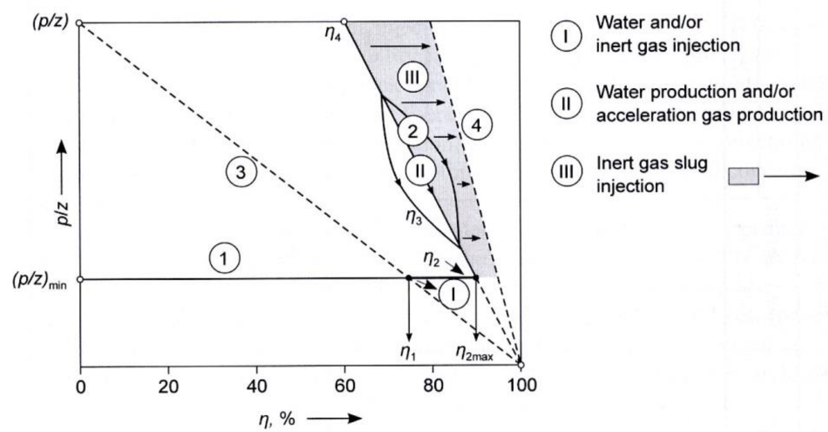

Figure 1.7b. EGR – IGR methods (Source: Pápay J. 2003)

The parameters in *Table 1.4* are as follows:

- η: gas recovery factor at abandonment conditions (–),
- η_v: volumetric sweep efficiency of encroached water (–),
- S_{gi}: initial gas saturation (–),
- S_{gr}: residual gas saturation (–),
- c: effective aquifer rock compressibility (1/bar),

as cond.cont.

(g/m^3)

.: <100

100-400

>400

Pápay J.-1997-2003

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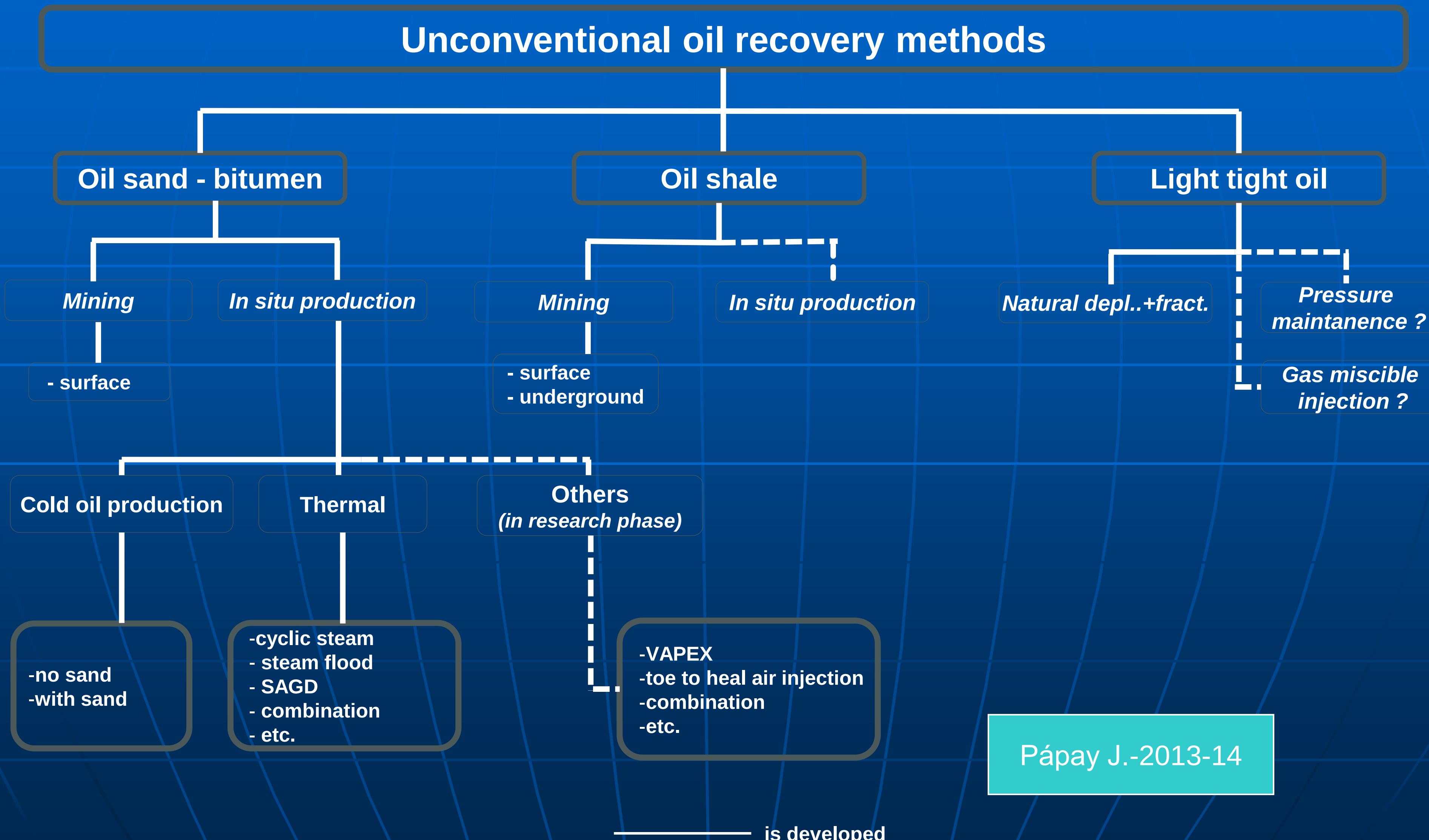
- Thank You


Unconventional oil recovery methods
Oil sand - bitumen
Oil shale
Light tight oil
Mining
In situ production
Mining
In situ production
Natural depl..+fract.
Pressure maintanence ?
Gas miscible injection ?
- surface
- surface
- underground
Cold oil production
Thermal
Others
(in research phase)
-no sand
-with sand
-cyclic steam
- steam flood
- SAGD
- combination
- etc.
-VAPEX
-toe to heal air injection
-combination
-etc.
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is developed

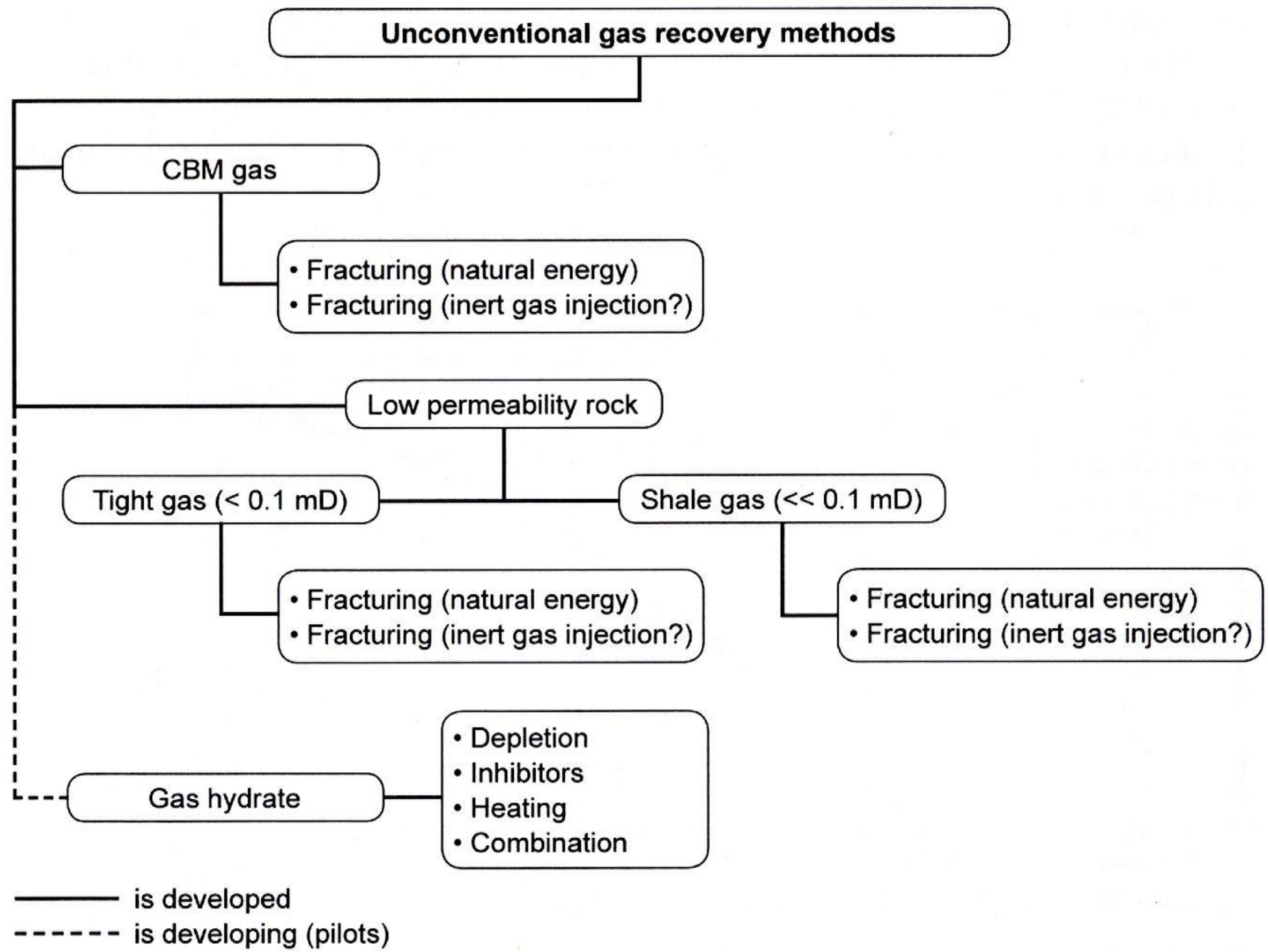

Figure 4.2. Classification of unconventional gas recovery processes

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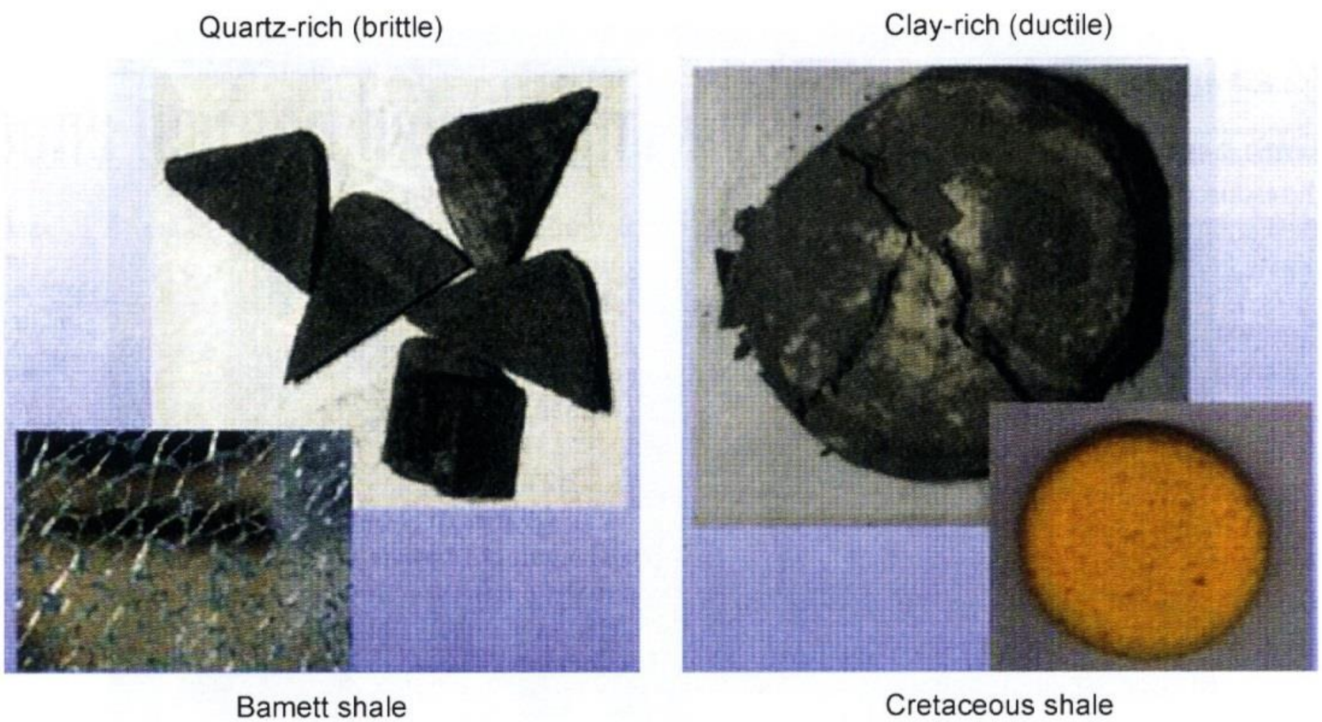

Figure 7.13. Shale mineralogy, stimulation effectiveness.
(Source: CSUG 2008, after Kuuskraa V.A. and Stevens S. 2009b)

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Recovery factors of different petroleum resources

Conventional petroleum (%)		
	Currently	Expectable (maximum)
Oil	33-35*	45-50*
Gas	75-80*	75-80*
Non conventional petroleum (%)		
Heavy oil & oilsand	(9-32) ** ill. (12-17)***	?
Oil shale	0?	?
Tight light oil	3-7 (min:1-max:10) *****	?
CBM	20-60****	?
Tight gas	10-50****	?
Shale gas	6-50****	?
Hydrate	0?	?

Note: * world average; ** USGS (2003); ***Soniere A., Lantz F. (2007); **** data of US ***** (EIA-2013)

Pápay J.-2011-14

Table 2a. Reserve and rate ratio of oil

	Conventional	Conventional + unconventional	
Reliability	Reserve / Rate years	Reserve / Rate years	Reserve / Rate years
Proved	43	48	48
Probable	62+7****	88+10****	69+8****
Possible	95	149	104
Reference	*	**	***

Notes: * USGS (2000), ** International Petroleum Encyclopedia (2006), *** Labastie A. (2010), **** spare (years).

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Table 2b. Reserve and rate ratio of gas

	Conventional	Conventional + unconventional	
Reliability	Reserve / Rate years	Reserve / Rate years	Reserve / Rate years
Proved	60	60	60
Probable	79+9****	132+15****	155+17****
Possible	115	235	283
Reference	*	**	***

Notes: * EIA (2005), ** IEA–WEO (2005 and 2009), *** IEA–WEO (2009), a new estimation comparing the total volume of $850 \cdot 10^{12}$ m^3 (55% conventional gas), **** spare (years).

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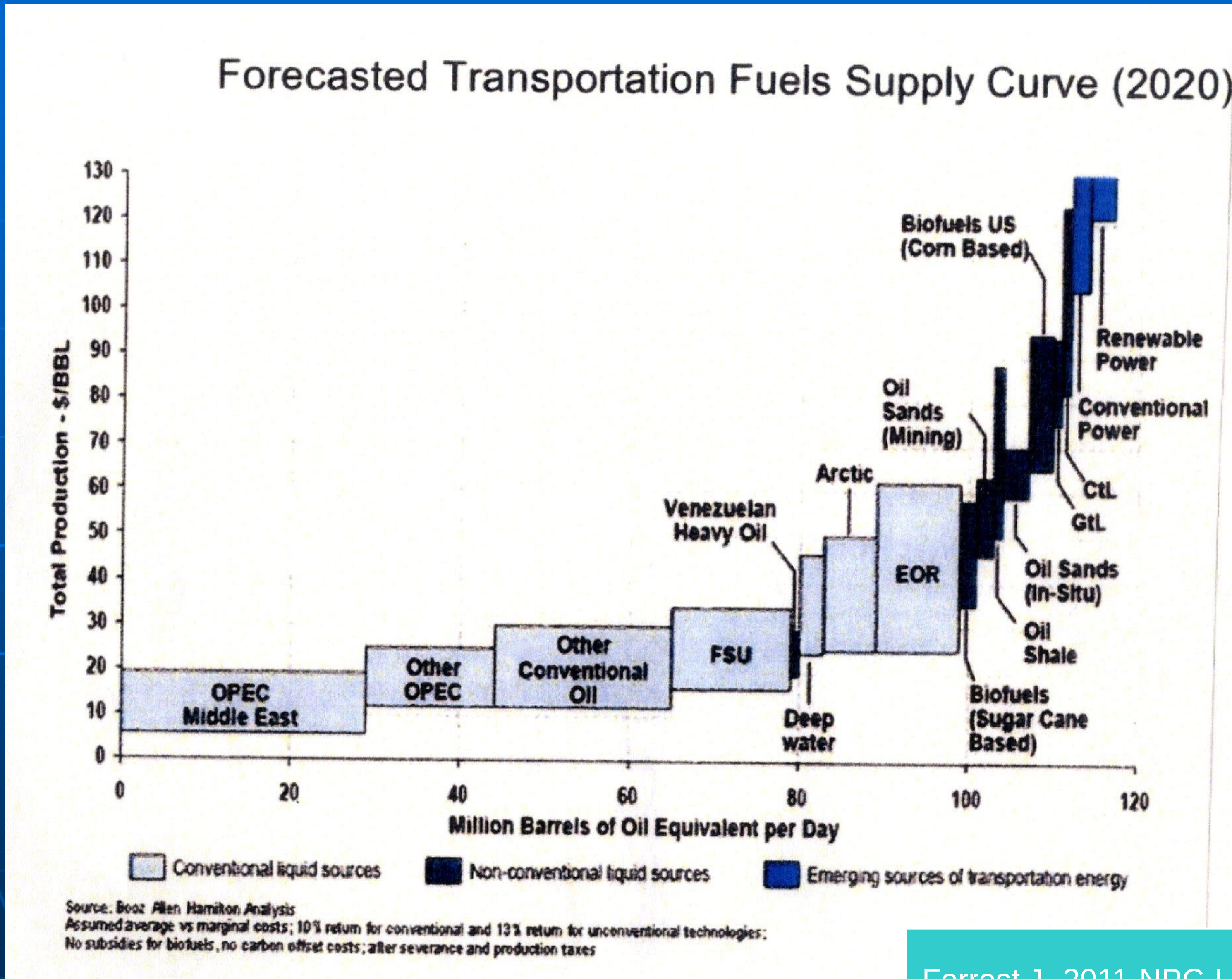

Forrest J.-2011-NPC-USA

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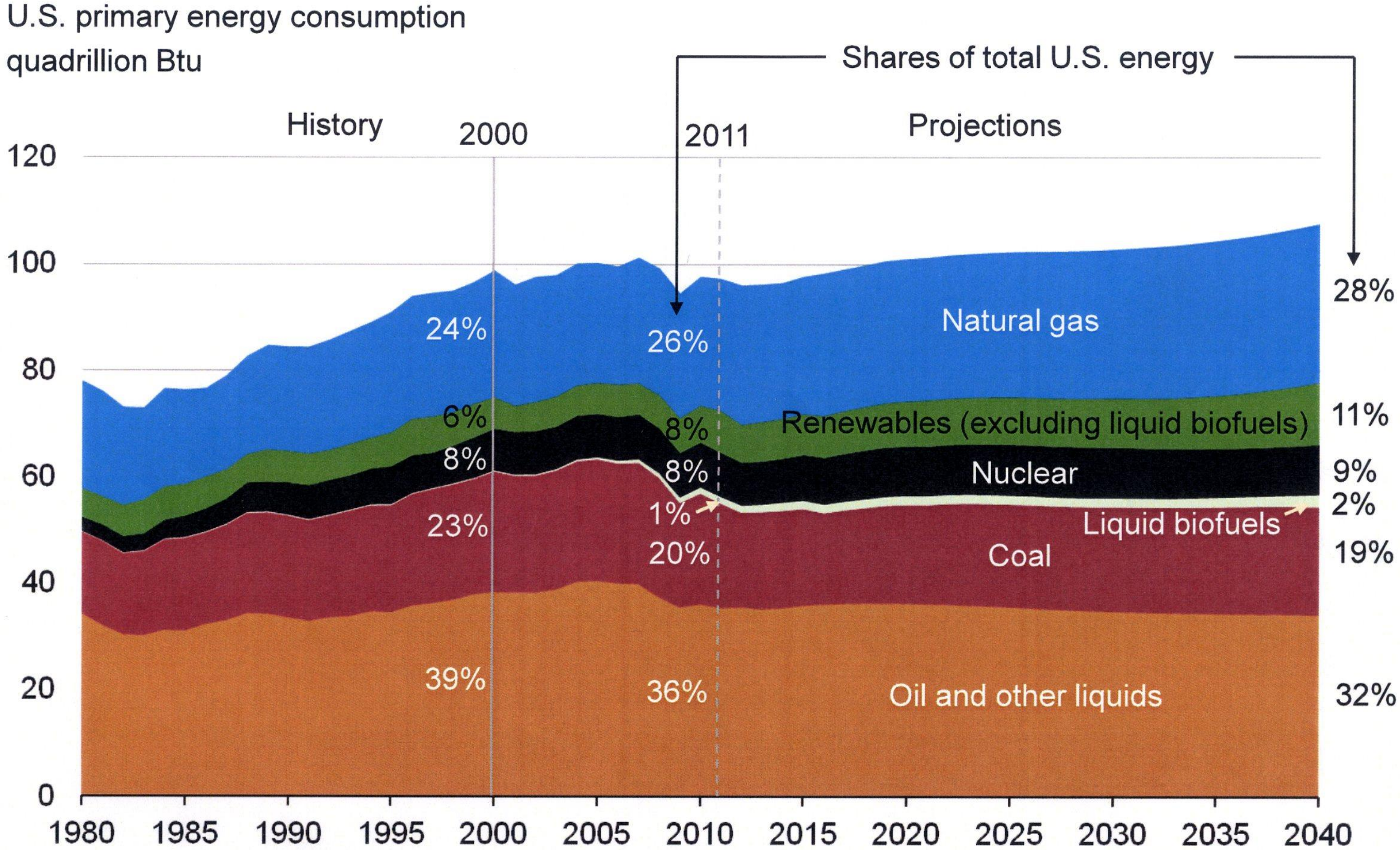
Table 4. Estimated petroleum production of the world

Million to/a

Years	2004	2020	2025	2050	2050	2100
Most likely		7,425	7,650	6,600	5,400	5,075
Maximum	6,189	9,500	9,600	9,400	8,000	7,100
Minimum		6,900	6,100	1,650	1,700	2,000

Schollnberger W.E..-2006

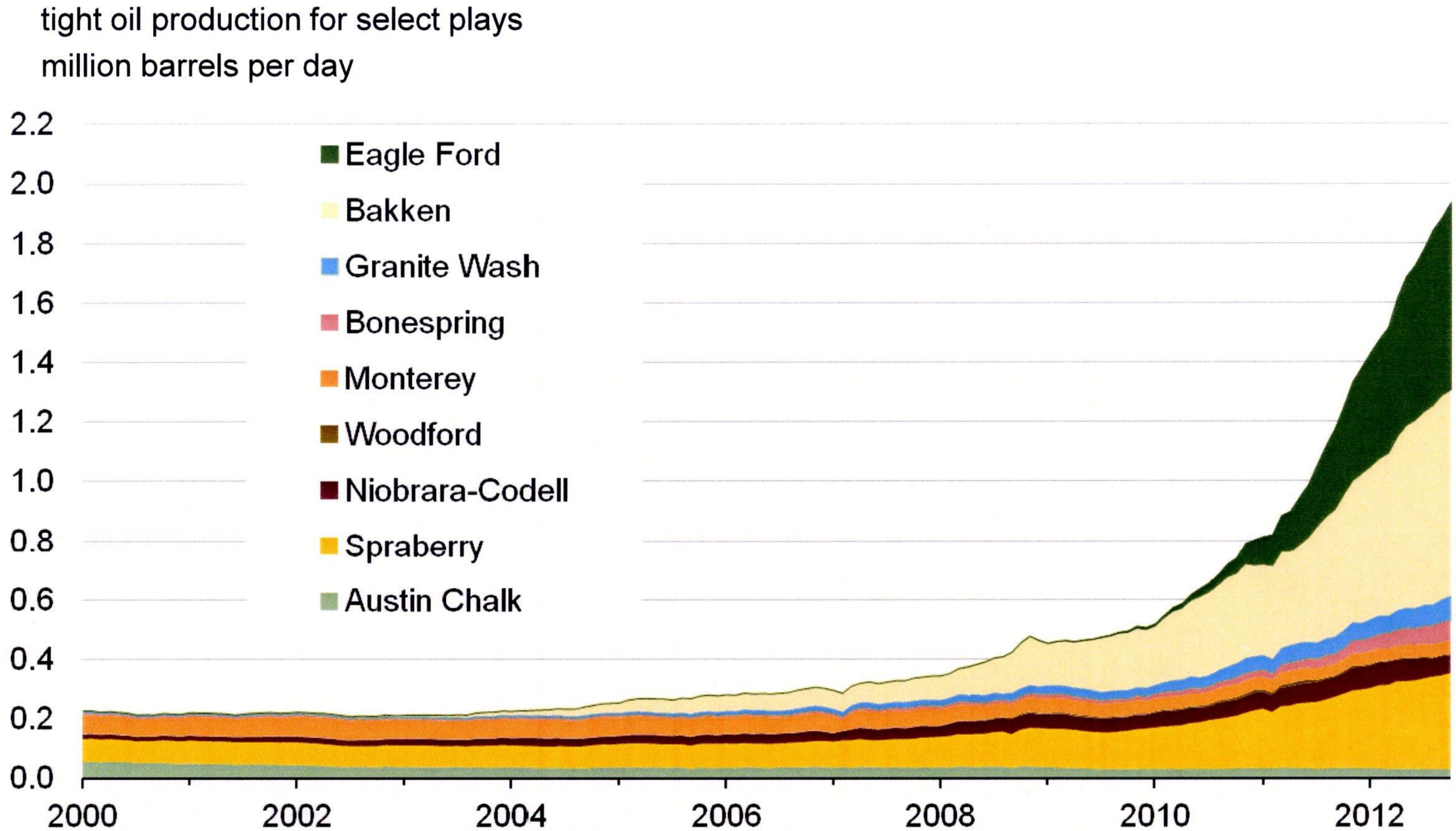
U.S. energy use grows slowly over the projection reflecting improving energy efficiency and slow, extended economic recovery



Source: EIA, Annual Energy Outlook 2013 Early Release

Sieminski A.-2013

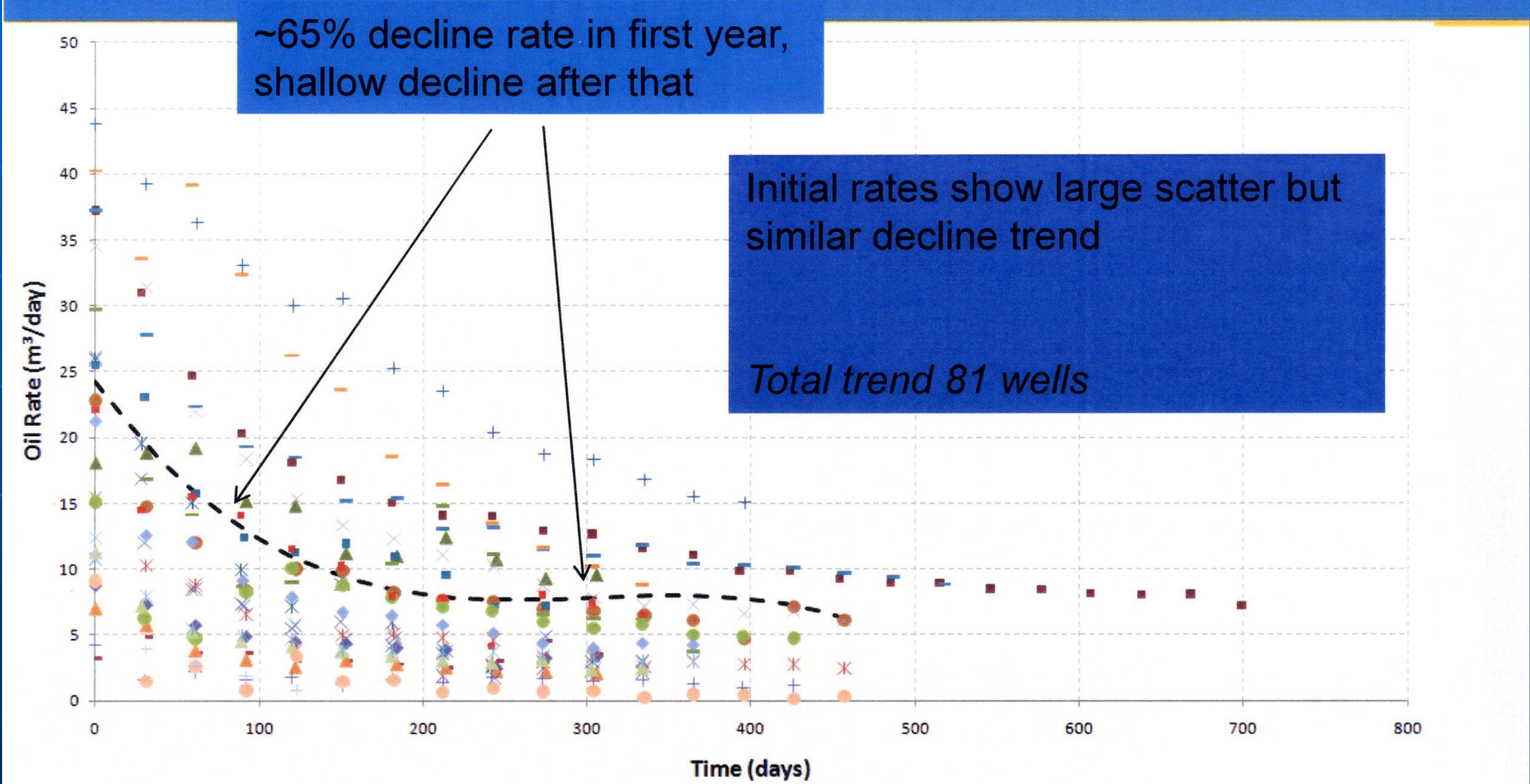
Domestic production of tight oil has grown dramatically over the past few years



Source: Drilling Info (formerly HPDI), Texas RRC, North Dakota department of mineral resources, and EIA, through October 2012.

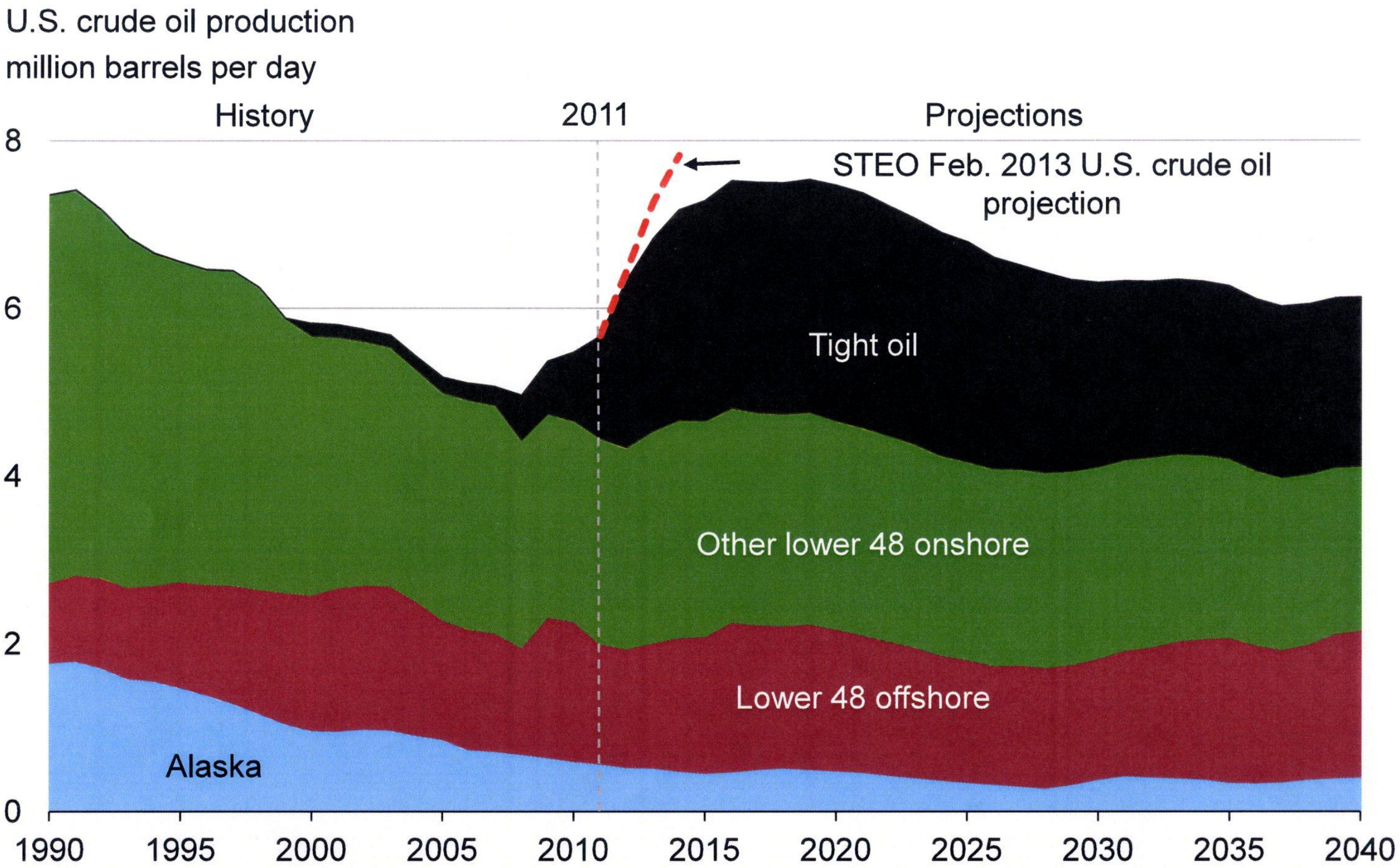
Sieminski A.-2013

Sample of Pembina Cardium Multi-Frac'd Wells



Backer R.-2013.05.13

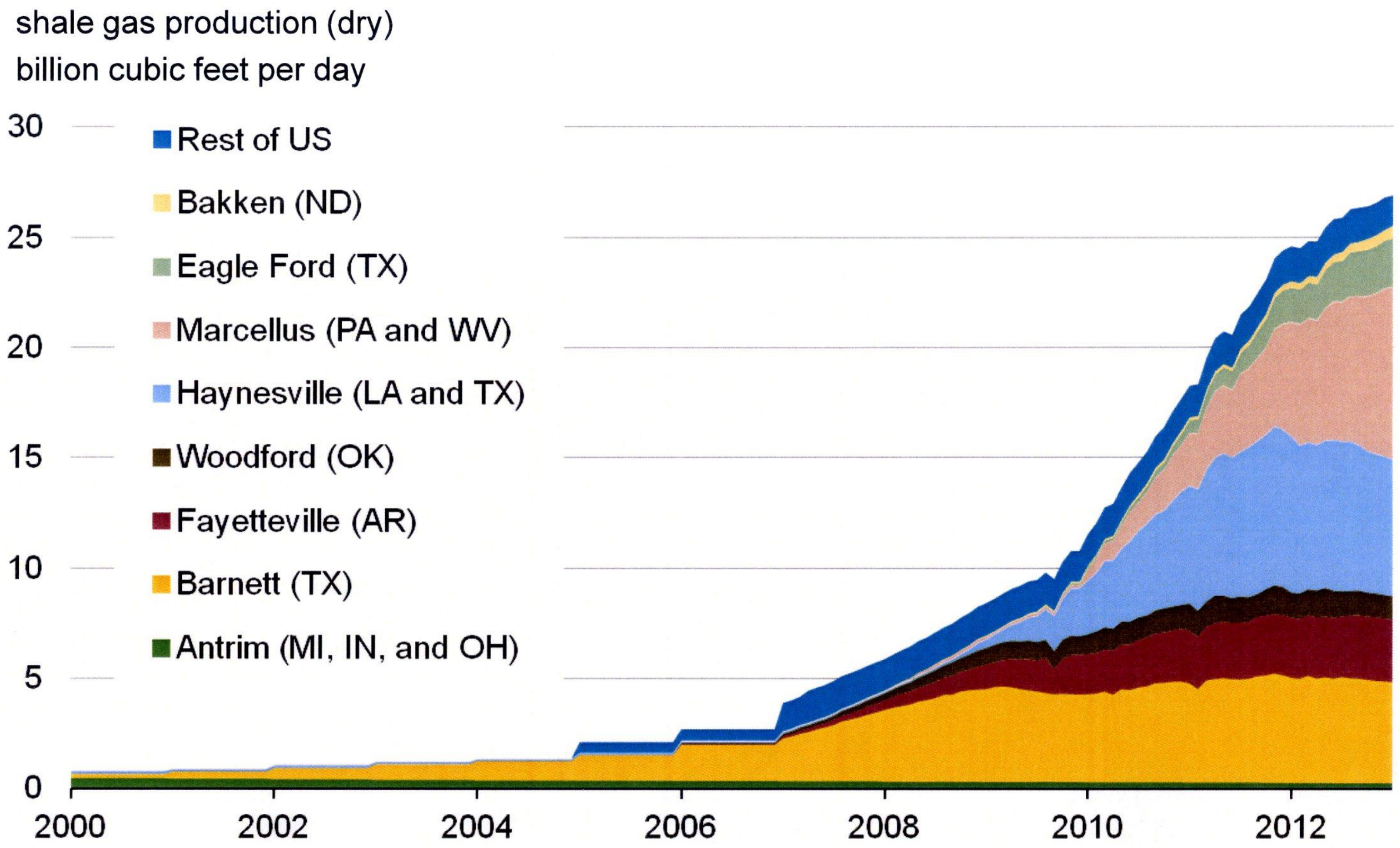
U.S. tight oil production leads a growth in domestic production of 2.6 million barrels per day between 2008 and 2019



Source: EIA, Annual Energy Outlook 2013 Early Release and Short-Term Energy Outlook, February 2013

Sieminski A.-2013

Domestic production of shale gas has grown dramatically over the past few years

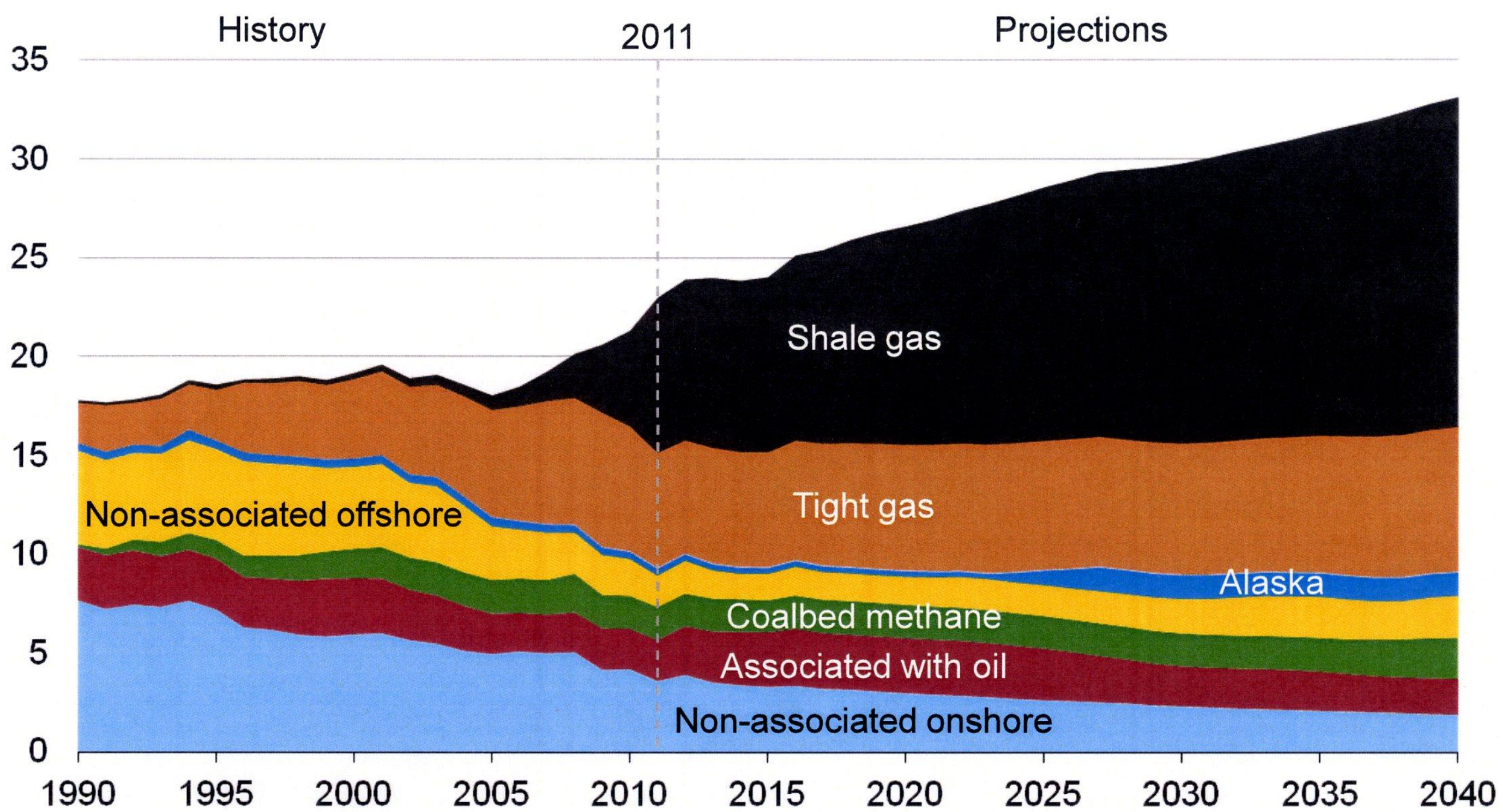


Sources: LCI Energy Insight gross withdrawal estimates as of January 2013 and converted to dry production estimates with EIA-calculated average gross-to-dry shrinkage factors by state and/or shale play.

Sieminski A.-2013

Shale gas leads growth in total gas production through 2040

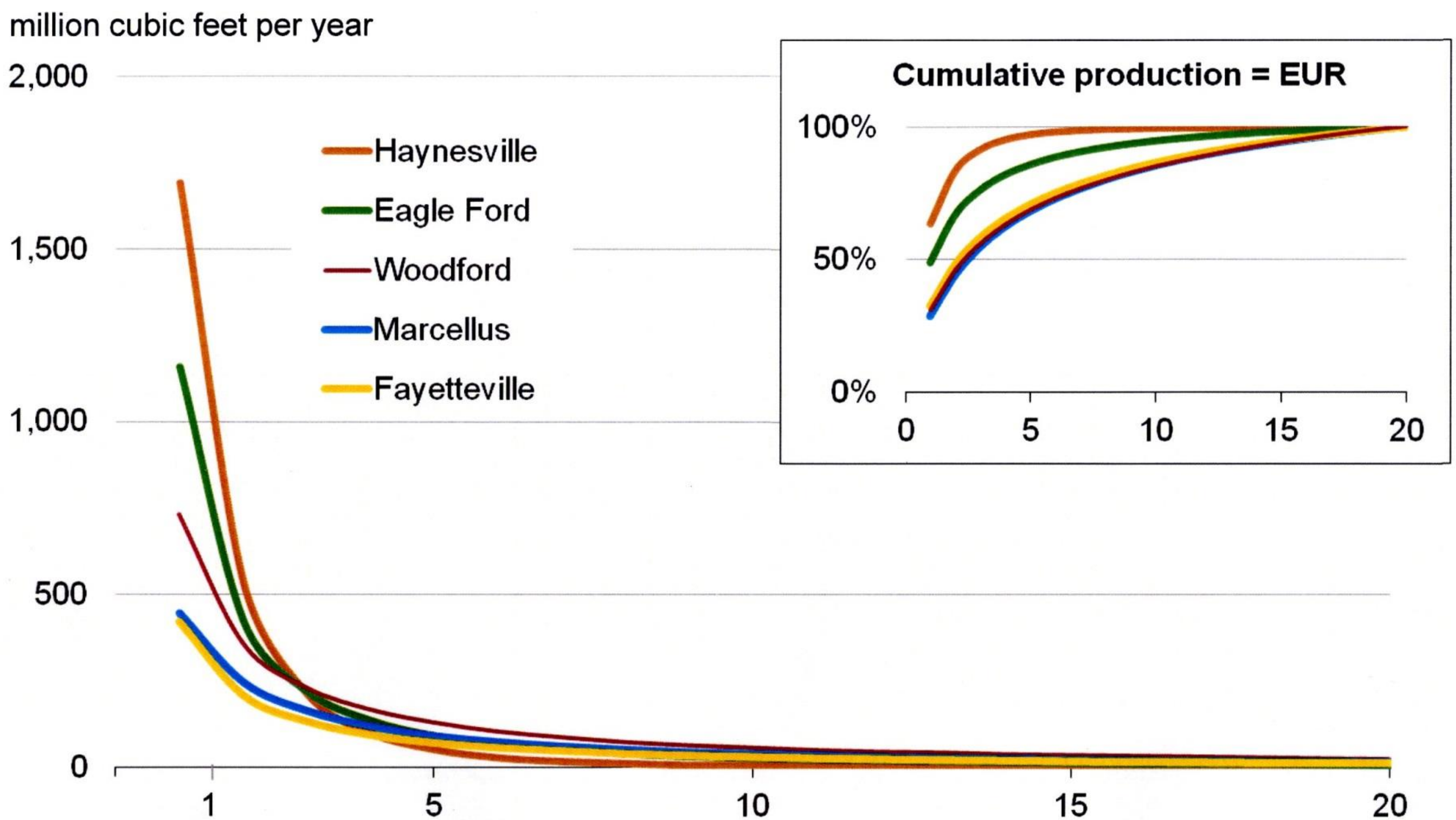
U.S. dry natural gas production
trillion cubic feet



Source: EIA, Annual Energy Outlook 2013 Early Release

Sieminski A.-2013

An average well in shale gas and other continuous resource plays can also have steep decline curves, which require continued drilling to grow production



Source: EIA, Annual Energy Outlook 2012

Sieminski A.-2013

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- **An overview is given about the petroleum recovery methods in an integrated way;**
- **Driving mechanisms of unconventional petroleum production is much more complicated as of concentional one;**
- **In case of unconventional petroleum accumulations - except oilsands- improved recovery methods are on laboratory or pilot scale only, therefore the recovery factors are low or modest yet;**
- **Exploitation of unconventional petroleum accumulation is a challenge for petroleum engineers;**
- **It seems that due to dynamic development of the research and the science the unconventional reserves step by step become conventional ones from the aspect of economy.**
- **Unconventional petroleum resources are already of primary importance to supply the energy demand**

Thank You