

# Shale: the unfinished revolution

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Reuters  
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“The shockwaves of rising U.S. shale gas and tight oil ... are reaching virtually all recesses of the global oil market ... These powerful forces are redefining the way oil is being produced, processed, traded and consumed around the world. There is hardly any aspect of the global supply chain that will not undergo some measure of transformation over the next five years” ([Medium-Term Oil Market Report](#), IEA, May 2013).

**Shale has revolutionised oil and gas supply and the geopolitical balance in less than five years, transforming the narrative from one about “peak energy” into a story about managing abundance.**

**2004:** “Gas production in the United States (excluding Alaska) now appears to be in permanent decline,” according to CERA (*The Worst is Yet to Come: Diverging Fundamentals Challenge the North American Gas Market*, Spring 2004).

**2005:** Hirsch Report for the U.S. Department of Energy warns about peaking global oil supplies and urges policymakers to learn lessons from the apparent peaking of gas production in the United States ([Peaking of World Oil Production: Impacts, Mitigation and Risk Management](#), Feb 2005).

**2008:** International Energy Agency (IEA) warns the oil industry will have to “run faster just to stand still” as a result of rising decline rates at aging super-giant and giant oil fields and expresses uncertainty about whether enough investment will be forthcoming ([World Energy Outlook 2008](#)).

**2011:** IEA asks “are we entering a golden age of gas?” and concludes the answer is a qualified yes (*Special Report* accompanying the [World Energy Outlook 2011](#)).

**2012:** “The economic and even political implications of this technological (shale) revolution, which won’t be completely understood for some time, are already significant,” according to the U.S. National Intelligence Council, which nonetheless described them as a “tectonic shift” that could yield energy independence for the United States ([Global Trends 2030](#), Dec 2012).

**2013:** Shale gas hailed as a “bridge fuel” while the United States develops zero-carbon energy sources for the future by U.S. Energy Secretary Ernest Moniz at his confirmation hearing ([Hearing of the Committee on Energy and Natural Resources](#), April 2013 ).

**2013:** “Hydrocarbon resources around the world are sufficiently abundant to fuel the world through its transition to a sustainable energy future” according to the IEA ([Resources to reserves: oil, gas and coal technologies for the energy markets of the future](#), May 2013).

**2013:** Shale resources will extend worldwide conventional gas reserves and resources by 47 percent and conventional oil reserves and resources by 11 percent, according to an assessment published by the U.S. Energy Information Administration (EIA) ([Technically recoverable shale oil and shale gas resources: an assessment of 137 shale formations in 41 countries outside the United States](#), June 2013).

**Shale resources are vast and distributed much more widely than conventional oil and gas fields**

EIA assessed resources in 137 shale formations in 41 countries outside the United States (but not including the major Caspian and Gulf oil and gas producers, which are thought to have substantial shale resources of their own)

### **Global gas resources (EIA 2013)**

Conventional gas reserves (proved)	6,741 trillion cubic feet (tcf)
Conventional gas resources (undiscovered)	8,842 tcf
Unconventional shale reserves and resources	7,298 tcf
Shale as percentage of total gas resources	32 percent
Projected life of global gas resources (present consumption rate)	196 years
of which shale resources	63 years

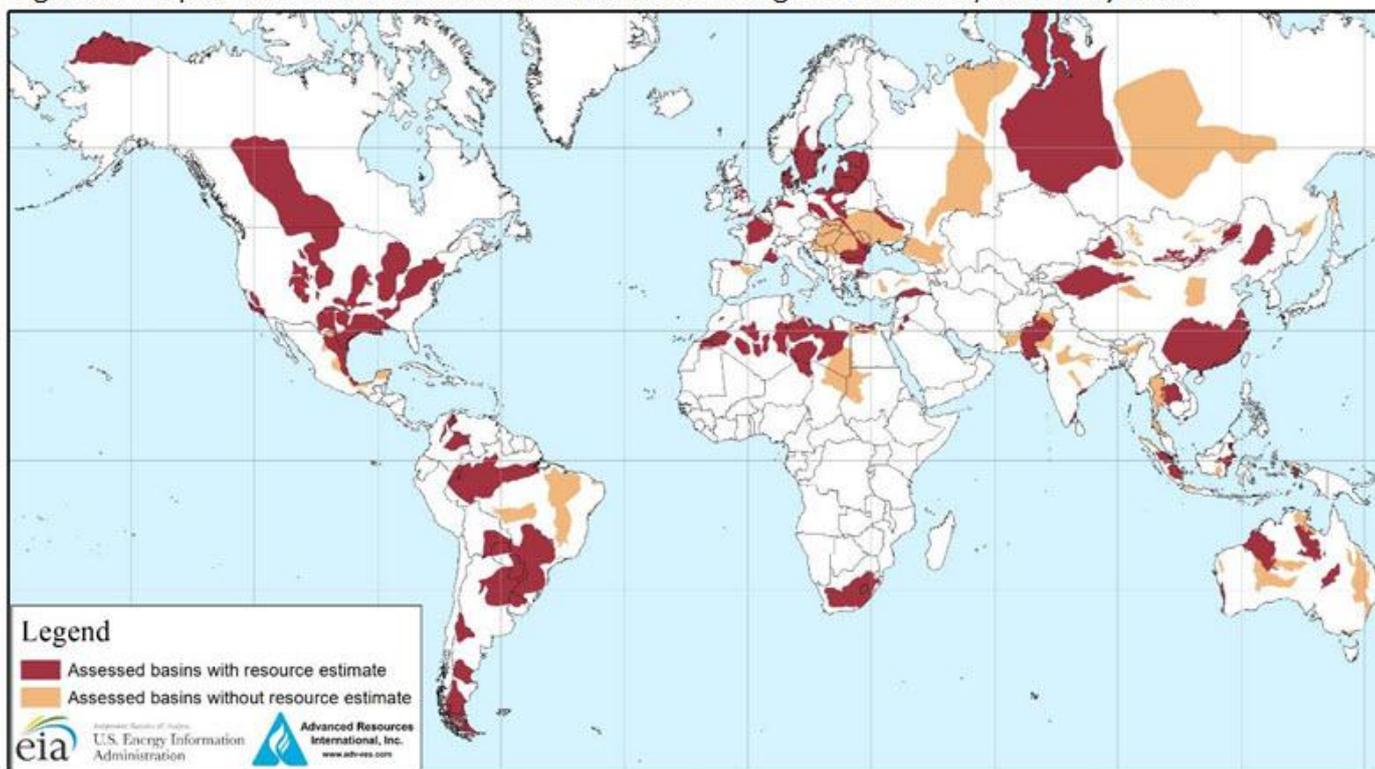
### **Global oil resources (EIA 2013)**

Conventional oil reserves (proved)	1,642 billion barrels
Conventional oil resources (undiscovered)	1,370 billion barrels
Unconventional shale reserves and resources	345 billion barrels
Shale as a percentage of total oil resources	10 percent
Projected life of global oil resources (present consumption rate)	100 years
of which shale resources	10 years

### **Distribution is what makes shale resources so interesting**

“Much of the shale resource exists in countries with limited endowments of conventional oil and gas ... or in countries where conventional hydrocarbon resources have largely been depleted” (EIA 2013).

Figure 1. Map of basins with assessed shale oil and shale gas formations, as of May 2013



Source: United States basins from U.S. Energy Information Administration and United States Geological Survey; other basins from ARI based on data from various published studies.

**If the technology's full potential is realised, shale resources could shift centre of gravity in the global oil and gas markets away from the Middle East, North Africa and Russia (for gas)**

**Top 10 countries with technically recoverable shale gas resources (EIA 2013)**

Rank	Country	Shale gas (trillion cubic feet)	
1	China	1,115	
2	Argentina	802	
3	Algeria	707	
4	U.S. <sup>1</sup>	665	(1,161)
5	Canada	573	
6	Mexico	545	
7	Australia	437	
8	South Africa	390	
9	Russia	285	
10	Brazil	245	
	World Total	7,299	(7,795)

**Top 10 countries with technically recoverable shale oil resources (EIA 2013)**

Rank	Country	Shale oil (billion barrels)	
1	Russia	75	
2	U.S. <sup>1</sup>	58	(48)
3	China	32	
4	Argentina	27	
5	Libya	26	
6	Australia	18	
7	Venezuela	13	
8	Mexico	13	
9	Pakistan	9	
10	Canada	9	
	World Total	345	(335)

<sup>1</sup> EIA estimates used for ranking order. ARI estimates in parentheses.

**Potential is global, but so far the only oil and gas produced hydraulic fracturing of shale has been in the United States**

Shale production confined to a small number of shale formations in the United States: Bakken and Eagle Ford (oil), Barnett, Haynesville, Marcellus (gas).

By 2012, shale production accounted for 29 percent of total U.S. crude production and 40 percent of total U.S. natural gas production.

Shale oil output neared 2 million barrels per day in 2012, from just 200,000 barrels per day in 2000. Shale gas output was up to 9.6 trillion cubic feet, from just 0.3 trillion in 2000 (EIA 2013).

Thousands of wells have been drilled and fractured into shale formations in the United States

Hardly any shale wells have been drilled let alone fractured in the rest of the world, including countries and basins which are thought to have the most resource potential.

Fewer than 50 wells drilled in **Poland**; only 4 fractured. **China** drilled and fractured only a couple of dozen in Sichuan/Chongqing (its most promising shale basin). **Britain** drilled four; fractured 1 (inducing seismic tremors which caused fracturing to be suspended for over a year). **Argentina** drilled only a handful in Vaca Muerta (“Dead Cow”). **France** banned fracking in Paris Basin because of environmental concerns ([Scaling-up shale](#), June 2013).

China’s programme for developing domestic gas (including shale) has fallen far behind the levels envisaged by the [12th Five-Year Plan](#), which aimed to double domestic consumption to 260 billion cubic metres by 2015, according to the IEA ([Gas pricing and regulation: China’s challenges and IEA experience](#), Sep 2012).

**Shale revolution stems from applying two mature technologies (hydraulic fracturing and horizontal drilling) in a new context to unlock oil and gas from well-known rock formations that were previously impossible to produce because of their low permeability**

**First well hydraulically fractured in Kansas in 1947.** Nearly all oil and gas wells drilled in the United States now fractured. By 2002, hydraulic fracturing had been used a million times, according to the National Petroleum Council ([Prudent development: realising the potential of North America’s abundant natural gas and oil resources](#)).

**Directional drilling has been possible since the 1920s** -- though the technology only became mature in the late 1980s. Drilling deviated, slant or crooked wells in the giant **East Texas** oil field in the 1950s and 1960s sparked biggest scandal in Texas history in 1962. Nearly 400 wells were illegally angled underneath neighbouring areas ([Oil, gas and government](#), 1995). **Wytch Farm** onshore oil field in England has horizontal oil wells snaking up to 11 kilometres under Poole Bay ([Petroleum geology of the south of England](#), 2013).

**Marine and lacustrine shales long known as organic rich source rocks** for oil and gas accumulations in conventional reservoirs but proved impossible to produce directly from them owing to their low permeability and porosity which led to poor well flow rates and made drilling uneconomic.

Reservoir permeability is measured in Darcies and ranges from highly permeable Middle East reservoirs through tight sandstones to shales

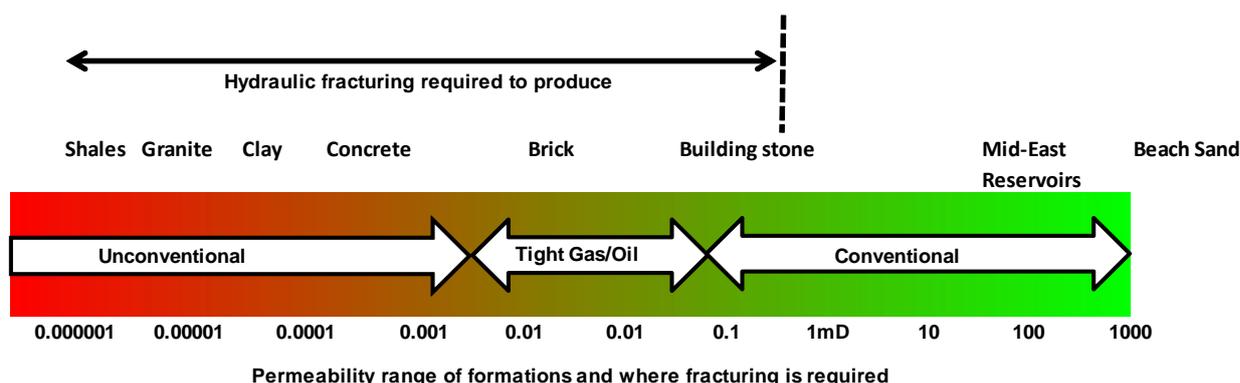


Chart adapted from [Hydraulic fracturing 101](#)

Horizontal drilling achieves much greater **contact** between the well bore and the reservoir. Horizontal wells can be drilled along the formation, rather than just through it.

Hydraulic fracturing artificially increases the **permeability** of shale and tight rock formations by creating a network of tiny fissures through which oil and gas can flow from a wide area of rock to the well.

**The key technological breakthrough came in the 1990s** when horizontal drilling and hydraulic fracturing were employed together for the first time in a systematic way by **Mitchell Energy** to start producing gas from the **Barnett shale** in Texas.

### **Horizontal drilling and hydraulic fracturing dramatically expand the range of possibilities for oil and gas production**

**Conventional** oil and gas exploration sought **discrete accumulations** of oil and gas where petroleum from a **source** rock had **migrated** and **pooled** in a **reservoir** rock trapped with a **seal**.

Conventional oil and gas explorers must find all four elements (thermally mature source rock, permeable migration pathway, reservoir formation, and seal) in the right geological sequence to find commercially drillable oil and gas fields.

**Unconventional** oil and gas production can **target the source** of oil and gas **directly** by going to the shale formations where oil and gas deposits are **continuous** throughout the formation rather than found in discrete pools, and where the shale acts as a combined **source, reservoir** and **seal**.

In North Dakota, for example, the **Bakken** shale (discovered 1953 but not extensively drilled until about 2005) is thought to be the source for much of the oil produced from conventional fields drilled into formations such as the **Madison** and **Red River** (which have been producing since the 1950s).

Horizontal drilling and hydraulic fracturing allow the same oil and gas to be produced but in a different and **less restrictive** way.

Continuous-type oil and gas formations are often discovered in the same **sedimentary basins** that have already been drilled for oil and gas by conventional methods (hence why traditional oil and gas-producing states like Texas and North Dakota have been at the heart of the shale boom).

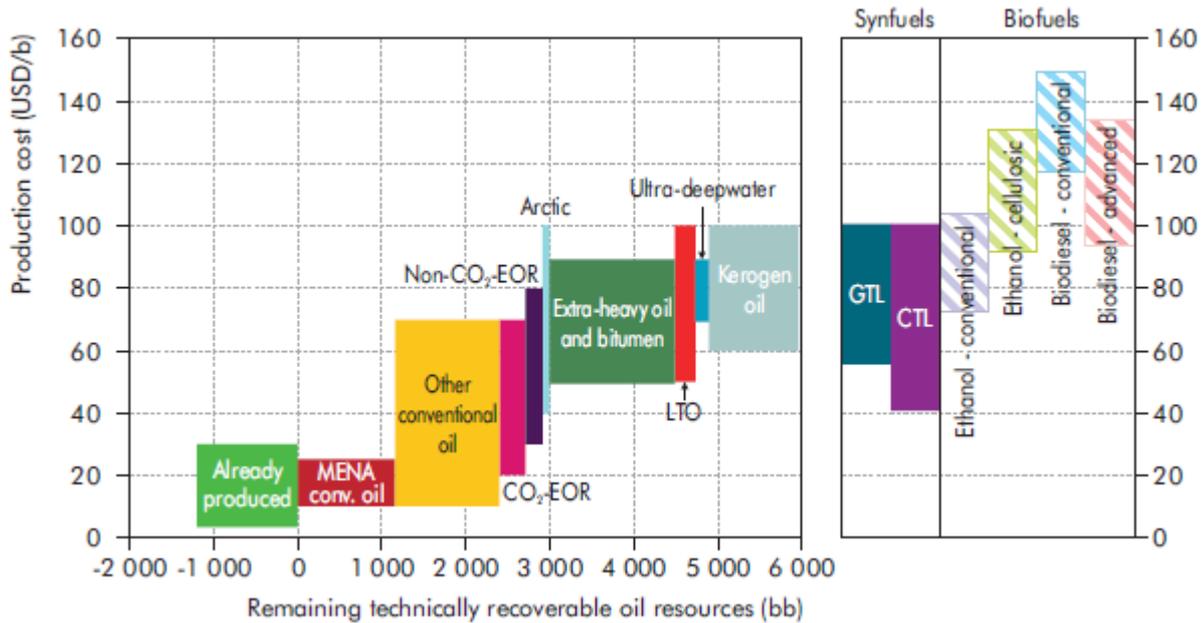
But horizontal drilling and hydraulic fracturing enable oil and gas to be produced from a much wider range of formation types over much bigger areas, which explains why shale oil and gas resources are more widely distributed than their conventional counterparts.

Unconventional oil and gas reduce **exploration risk** because the probability of drilling a completely dry well is lower. Most wells will flow at least some oil and gas, though production from different wells drilled into the same formation is very variable, even across quite small distances. The big returns come from finding **sweet spots** in the formation with unusually high flow rates.

Shale is a **disruptive technology** because it has emerged in the middle of the cost-curve, and will displace higher cost oil and gas production

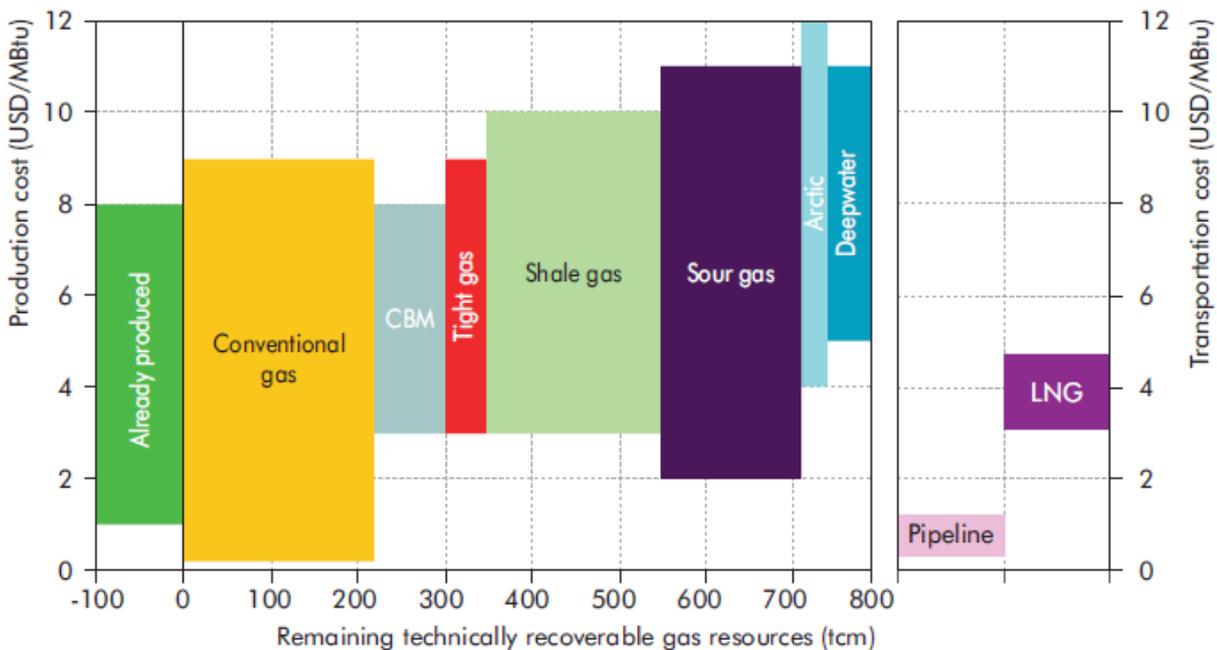
IEA cost curve for various types of crude oil production ([Resources to reserves](#), 2013)

**Figure 8.3 • Oil production costs for various resource categories**



IEA cost curve for various types of gas production ([Resources to reserves](#), 2013)

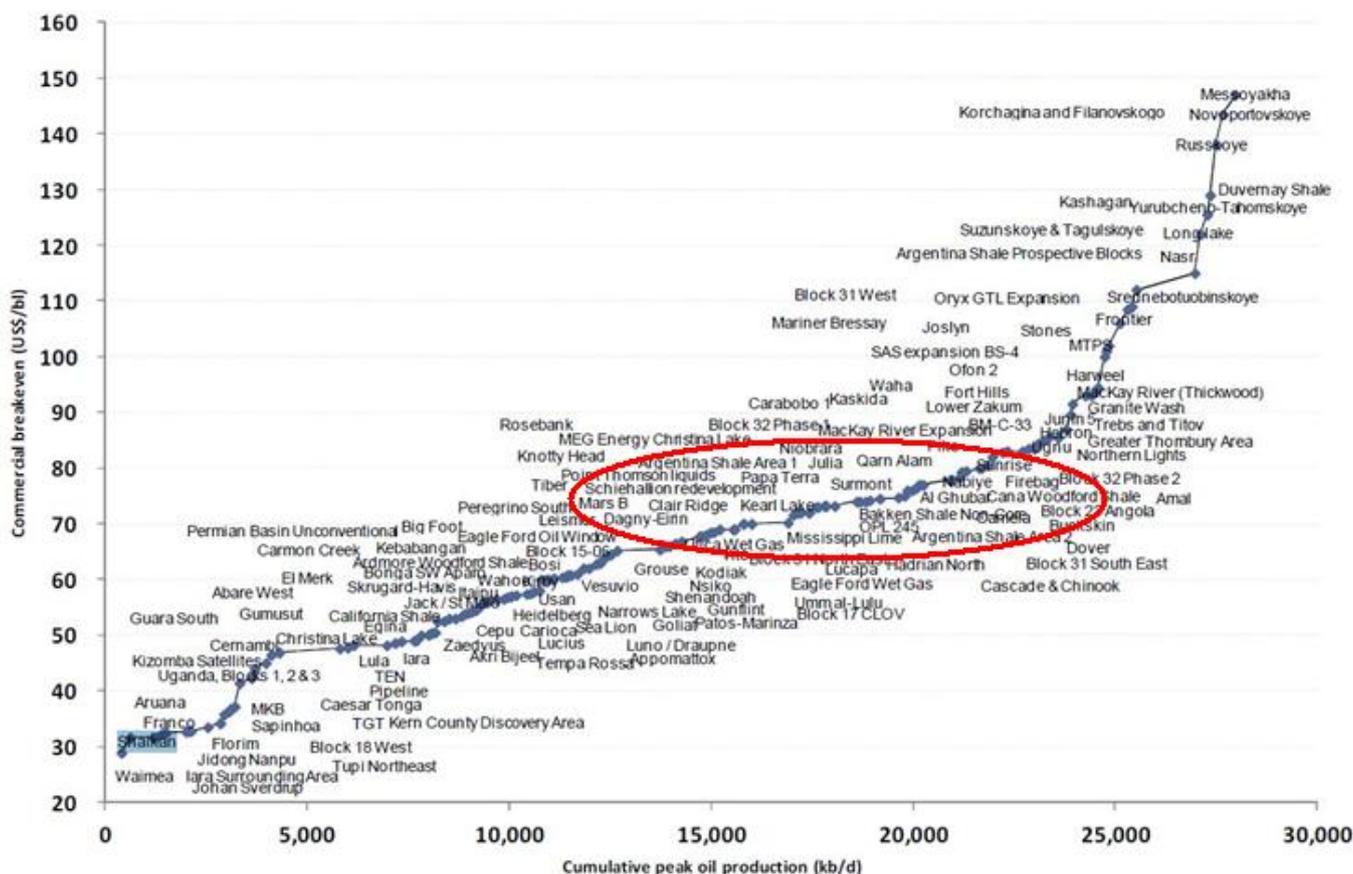
**Figure 8.4 • Long-term gas supply cost curve**



Cost estimates vary, but shale production could cost as little as \$3-4 per mmBtu and \$50-60 per bbl.

Cost curve from Goldman Sachs (Oct 2012) --with shale breakeven area added

Commercial breakeven for the Top 360 oil projects



Estimates for the long-term sustainable price of oil and gas have been revised sharply lower as a result of the availability of large amounts of comparatively cheap oil and gas from fracturing operations. Expectations now anchored around long term prices <\$100 per barrel and <\$6 or <\$8 per mmBtu (at least in North America).

**Shale is disruptive because it reverses the previous trend towards producing heavier and sourer crudes -- but is a poor match for a world where mid distillates are in high demand**

**Prior to 2009**, the marginal barrel of crude oil demanded by refineries was light-sweet (as a result of increasingly stringent environmental regulations) but the marginal barrel supplied by producers was heavy-sour and expected to become even more heavy and sour in future (with marginal supply expected to come from the Middle East as well as Canada and Venezuela).

Result was a shortage of light crudes and a wide heavy spread and spiking prices. Refiners on the U.S. Gulf Coast, the Middle East and Asia invested heavily in cokers and other upgrading capacity to enable them to handle heavier crudes and strip out all the undesirable sulphur.

**Since 2011**, shale revolution has upended these planning assumptions. Marginal barrel of oil supplied is increasingly light and sweet, while refiners increasingly need medium and heavier crudes to maximise diesel output.

Dieselisation policies in Europe have produced a major imbalance in the world fuels market. Ethanol blending and tougher vehicle efficiency standards have intensified the pressure by tilting demand even more towards mid-distillates and away from gasoline.

The surge in shale oil production, which is more suitable for producing gasoline than diesel, has compounded the problem.

Result is a **worldwide abundance of light crudes** and a **sharp narrowing of the light-heavy spread**. Export restrictions ensure that U.S. shale oil cannot be sent abroad. But surging shale oil production has backed out a large volume of previous imports from light crude producers like **Nigeria** and **Algeria**, and sent them hunting for new markets in Europe and Asia.

“U.S. light tight oil ... is causing an unexpected quality shift in the global crude mix. While many supply growth forecasts had long been predicated on the notion of a shift in crude quality towards heavier and sourer grades, light tight oil is exceptionally light and sweet. While a good fit for some U.S. refineries which had seemed on the brink of closure, the supply boom is proving a challenge as well as an opportunity for others, which had bet on a widening of the heavy-light price spread and invested massively in upgrading capacity,” according to the IEA ([Medium-Term Oil Market Report](#), May 2013).

### Shale is disrupting policy on climate change

Shale gas is seen by some policymakers as a **cleaner alternative to coal** and a **bridge fuel** until the energy system can move towards even cleaner zero-emissions technologies in future decades.

Obama administration has embraced shale gas (and to some extent oil) as part of its **“all of the above”** strategy on energy and climate change.

Shale gas has contributed to the **decline in U.S. CO2 emissions** by replacing coal combustion in power generation.

But **growing U.S. coal exports** have contributed to **low coal prices** and **record coal combustion in Europe** and especially **Asia**.

**Controversy** over how much **methane** (which is 25-72 times more potent than CO2 as a greenhouse gas) is being **vented** from shale wells during the initial flowback period following completion.

Shale is contributing to an **abundance of cheap fossil fuel energy** (oil, gas and coal) that **threatens** to undercut international efforts to limit global warming to **2° C** by 2050.

Prior to 2011, policymakers were counting on peaking oil and gas production and sharply rising prices to help limit consumption and spur the transition to cleaner alternatives. Fears about peak oil and climate change were in a strange way complementary.

Now fossil fuels will remain plentiful and cheap enough to cook the planet many times over.

### “Carbon budget” developed by the IEA

Max. CO2 emissions 2000-2050 to limit temp. rise to 2° C	1,440 billion tonnes CO2e
CO2 already emitted 2000-2011	420 billion tonnes CO2e
Other non-energy emissions to 2050	136 billion tonnes CO2e
Remaining CO2 budget to 2050	884 billion tonnes CO2e
Current proven and probable oil+gas+coal reserves	2,860 billion tonnes CO2e

If governments are serious about limiting the rise in temperatures to 2°C by 2050, **two thirds of currently known oil, gas and coal reserves will have to remain in the ground**, according to the IEA ([World Energy Outlook 2013](#)).

**Shale is transforming the United States from the world's largest energy importer to a significant exporter in at least some areas**

Natural gas exports have tripled in the last decade, and the U.S. has emerged as a substantial exporter of diesel and other petroleum products, according to Senator Lisa Murkowski of Alaska, the highest-ranking Republican on the Senate Energy and Natural Resources Committee ([Keynote address to EIA annual conference](#), June 2013).

**In 2005**, U.S. Department of Energy was considering applications for permission to build up to **15 LNG import terminals** to meet demand as domestic supplies peaked and declined.

**In 2013**, U.S. Department of Energy has approved or is considering applications to build **27 LNG export terminals** to export surplus domestic gas production.

United States is already exporting increasing volume of condensates (propane, butane) produced along with shale gas and oil.

“The more complicated debate will be over crude oil exports. We won't see it this summer, but we will see it soon. And if we don't handle LNG exports in the right way, with sensible data-driven analysis, then there is little hope we will be able to tackle a hot-button issue like crude oil in a way that escapes the din and strife of partisan squabble” according to Sen. Murkowski ([Keynote address](#), June 2013).

IEA Executive Director Maria van der Hoeven has already called for the U.S. to permit crude oil exports to ease the mismatch between rising domestic production of light crude and the configuration of many U.S. refineries to process heavier, sourer oils ([Obstacles in the path to a U.S. oil boom](#), June 2013).

“U.S. crude exports are subject to stiff restrictions, and America's refiners can only absorb so much of the new supplies,” according to van der Hoeven.

“The U.S. refining industry has in effect become a conduit for crude oil exports, allowing rising U.S. crude production to be exported in product form. In just seven years, the U.S. has tripled the amount of products it exports, transforming itself from the world's top product importer to second-largest product exporter, surpassed only by Russia.”

“Effective as U.S. refiners may have been in mopping up the additional supply and sending it overseas, they have limited capacity to absorb additional barrels of high quality light, low sulphur oil”

“Market realities suggest a far simpler decision ahead: either U.S. crude is shipped abroad, or it stays in the ground” ([Obstacles in the path to a U.S. oil boom](#), June 2013).

**Cheap shale gas is conferring a competitive advantage on U.S. manufacturers, especially those in energy-intensive trade exposed (EITE) industries such as iron, steel, chemicals and plastics**

U.S. manufacturers have announced **\$95 billion** in capital projects based on the new assumption about an affordable supply of natural gas and gas-fired power, according to the Industrial Energy Consumers of America (IECA) ([Response to LNG Export study](#), Jan 2013).

New steel and direct reduced iron plants announced for the U.S. Gulf Coast and Mid-Atlantic states.

Policymakers talk up the possibility for a “manufacturing renaissance” and return (onshoring) of at least some production lost during the 1990s and 2000s to China.

EU business organisations and politicians express concern about the competitive disadvantage which high energy prices in Europe are imposing on local manufacturers compared with United States

Is shale blunting the EU’s former enthusiasm for investment in clean technology and carbon pricing?

## **Shale is disrupting the geopolitical balance**

### **Pre-shale order (2008)**

U.S. relies on crude and natural gas imports to meet a large and growing proportion of its energy needs

U.S. is world’s largest crude oil importer

Energy is seen as key strategic vulnerability

Power projection into the Middle East at least in part to protect oil supplies

Power projection along shipping lanes to protect key supply routes

OPEC (especially MENA) seen as accounting for an increasing share of oil production and reserves in medium term

### **Post-shale order (2013)**

North America (U.S. plus Canada and Mexico) likely to become self-sufficient in oil as well as gas and coal by 2020

U.S. is emerging as a significant energy exporter (gas, refined products, maybe eventually crude)

Cheap and plentiful oil and gas supplies seen as a source of strategic advantage

U.S. trade deficit in petroleum and refined products starting to narrow

“Abundant energy at home means that we have a real opportunity to greatly enhance our nation’s global posture in energy markets,” according to Sen. Lisa Murkowski ([Keynote address](#), June 2013).

Debate over the meaning of energy independence

U.S. strategic interests in the Middle East and overseas must change, though policymakers deny any retreat in U.S. involvement in the Persian Gulf region

OPEC’s power diminished by growing competition from shale supplies

China has overtaken the United States as the world’s largest crude oil importer, and the country most heavily reliant on oil from the Middle East.

China rather than the United States is most vulnerable to any interruption in oil supplies or sudden spike in prices

China looking to strengthen strategic posture in the Middle East and develop capability to safeguard vital sea lanes ([China and the world oil market](#), Feb 2013).

Comparative abundance of gas (4 trillion bbl equivalent) compared with crude oil (3 trillion equivalent) could cement long-term shift to employing gas as a transport fuel

**CONCLUSION: Shale is a profoundly disruptive technology. It touches everything in the global oil and gas markets: production, costs, refining, transport routes and the balance of power. And the revolution has only just begun**

**The question is how fast the industry can be scaled up and spread beyond North America: most of the key obstacles are “above ground” (politics, environmental acceptability, legal and regulatory framework) rather than geological or technical**