China’s heft in the global crude oil market exerts profound global effects across the energy, environmental, and human well-being dimensions. Yet comprehensive, high-frequency, reliable, and publicly available data on China’s domestic oil flows and inventory movements are essentially inaccessible. In particular, for on-the-ground primary commercial intelligence collection, such as that performed by Genscape and other independent analytical companies in the U.S. market, China’s oil sector is effectively a “denied area.” This is not because the data themselves do not exist or aren’t being collected. Rather, it is a challenge at its core rooted in:

1. the Chinese government’s obsession with secrecy and maximum control of information; and
2. data costs. The prime purveyors of insights derived from satellite imagery are generally startups that must first answer to investors seeking returns and are thus often economically constrained from sharing data at a price point low enough to allow large-scale analysis of China’s energy sector by academic parties and various NGOs.

Many of the puzzle pieces already exist for high-quality public domain analysis of oil sector flows in China. For instance, the Joint Organisations Data Initiative (JODI) publishes monthly data for estimated oil flows and refined product usage in China, albeit with several months of delay and without specifying flow data by location, a potentially critical omission. The Global Energy Observatory project offers limited data on part of China’s oil refinery fleet and the country’s main oil ports. TankerTrackers offers insights into various global seaborne oil flows.

However, the specific oil storage data and other information that would improve analysts’ ability to ascertain flow patterns within China are not disclosed by the Chinese government in a regular and comprehensive fashion, leaving analysts to try and piece together numerous missing pieces of a very large and complex oil puzzle. In response to this globally important omission, we propose creating a forum to more systematically collect and analyze satellite data capable of shedding more light on the inner workings of China’s oil sector. Such imagery can be fused with other data sources and cross-analyzed, with the aim of yielding a level of insight into China’s oil inventory and flow dynamics that would be exponentially deeper than the current general state of knowledge.

An open-source forum of academic, think tank, and government participants would present an ideal channel for aggregating and analyzing the data in a systematic and useful manner. It could leverage and build upon the formidable existing experience of the US Energy Information Administration (EIA) and the
Better data transparency would benefit oil producers and consumers both within and outside of China. International Energy Agency (IEA), both of which already closely track oil sector activity in China as part of their analytical mandates. Neither entity has a proprietary interest in the oil markets, which enhances their ability to cooperate with academic and other participants whose core interests often center on publishing both analysis and the underlying data themselves. The discussion below outlines how such an approach adds value to analysis of global flows and also explores the potential costs and execution challenges that would need to be overcome.

SATELLITE DATA CAN HELP SURMOUNT THE “GREAT WALL OF SECRECY”

Making high-quality satellite imagery available to the broader global energy research community can help crack open the “Great Wall of Secrecy” and improve data transparency and insights into the inner workings of the world’s second-largest crude oil market.

To illustrate the problem at hand, consider that data reported by Xinhua—China’s sole officially sanctioned oil inventory data source—only track oil stored in “commercial tanks.” Satellite data from Orbital Insight raise serious doubts about how thorough—and thus useful to the market—this Xinhua data really is. For instance, at times in mid-to late 2017, Orbital Insight’s data suggested total crude oil stockpiles in China were more than three times as large as the figures reported by Xinhua—a potential discrepancy of more than 500 million barrels. That is enough oil to fill more than 250 very large crude carriers (i.e., “supertankers”). Furthermore, the Xinhua data stream shows relatively little variability in storage volumes over time. One would expect inventory to be the mechanism through which the country’s oil sector balances these shifts, with commensurately large monthly storage movements, such as those that periodically appear in satellite-derived storage data. Thus, the unusually stable Xinhua inventory data trend line raises questions, given that China’s oil import volumes, which account for two-thirds of its total crude supply, can shift significantly month-to-month.

Better data transparency would benefit oil producers and consumers both within and outside of China. For example, OPEC producers seeking to achieve a certain price range, US shale producers contemplating hedging programs, and China–based refiners all would benefit from broader data transparency. Investment decisions—especially in a market as large and complicated as the global oil market—are never made with a truly “complete” set of information. That being said, relative improvements to information availability from one of the market’s most important participants can have broad positive effects. More granular and complete Chinese oil data would help better inform oil producers and processors as to happenings in a marketplace that now accounts for roughly 1 out of every 8 barrels of oil used globally. In turn, this would likely have a stabilizing impact on crude oil pricing through improved signals to the market. Both producers and consumers would ultimately benefit over the long-run.

In this respect, improved data availability also harmonizes well with Beijing’s current political priorities. The costs of oil price spikes arising from the market’s reaction to “surprises” in supply and demand fall heavily on Chinese consumers, given the country’s rising import dependence. Making available more regular, accurate, and granular data from the world’s second-largest oil consumer and seventh-largest producer stands to reduce the frequency and magnitude of such surprise-driven price volatility.

Additionally, China would like to establish a local oil trading hub to help bring price discovery closer to home. But without better data transparency, it will be tough to reach liquidity levels sufficient to pull traders away from established hubs in New York, London, and Singapore.

WHY EMPHASIZE SATELLITE DATA?

Researchers can now access earth observation data from satellites that even 10 years ago were basically only available to
government agencies and a few specialized and well-funded corporate actors. Accordingly, China’s draconian restrictions on detailed oil-sector data collection are becoming increasingly untenable. Now, a single rocket launch can place a flock of 88 privately owned earth observation microsatellites in orbit. And to boot, these “eyes in the sky” are becoming sharper. Computer vision has advanced to the point that machines can deduce oil inventory levels by analyzing the movements of floating oil storage tank roofs over time. They can also locate drilling locations in places as remote as South Sudan, and even identify individual frac water storage pits.

Satellites passing repeatedly over the same area can provide a time-lapse image series that can help identify the construction of roads and pipelines, well completions, drilling rig movement, and other important energy-related activities.

Assessing changes over time allows analysts to zoom in on patterns of activity—for instance, how much time elapsed between the first appearance of a dirt drilling pad and the presence of a drilling rig or final production equipment, etc. Fusing this type of primary and derivative information with other data sets can allow analysts to glean deep insights into both company-level operational patterns and macro-level activity.

Furthermore, Beijing cannot control access to such satellite information unless it wishes to launch an extraterritorial campaign against satellite image providers and their employees/investors—which it would have no legitimate, internationally recognized legal basis to do—or decides to physically shield energy sector infrastructure from satellite view. Such an approach might work for concealing selected high-value military assets, but it is almost certainly cost-prohibitive in the case of production fields, tank farms, refineries, and pipeline networks spanning one of the largest countries in the world by land area.

Even if data gatherers on the ground in China can be constrained by the risk of severe physical penalties, Chinese officials can do little to prevent remote sensors in space from gathering data on energy sector activities. Such increased data access offers real value across the policymaking and commercial spectrums, as imagery and derived data become a critical resource for tracking oil inventory changes and flow patterns within China.

Even for highly motivated, deep-pocketed commercial parties such as oil traders and hedge funds, access to reliable high-frequency China oil data at a provinciwide and nationwide scale is often constrained. The restraints on data availability are even more acute for the academic, governmental, and policy communities outside of (and within) China, whose insights and contributions will be crucial to developing solutions to China-centric energy challenges with global impacts.

There is a nearly decade-long history of non-governmental organizations leveraging satellite data to help improve policymaking on issues with profound regional, and in some cases, global, consequences. For instance, the Satellite Sentinel Project, founded in 2010 by actor and philanthropist George Clooney and human rights activist John Prendergast, has utilized imagery from DigitalGlobe to help detect evidence of mass violence in Sudan and South Sudan. Likewise, Global Forest Watch has used space-based imaging since 2014 to monitor deforestation and other actions “in near real-time.”

China’s oil sector merits similar attention, given the current lack of comprehensive data disclosure and the reality that what happens in China’s domestic oil space often reverberates globally.

**HOW WOULD THE SATELLITE DATA BE UTILIZED?**

First and foremost, satellite data showing oil inventory changes would help fill in currently massive gaps in the publicly available data on changes in crude oil storage levels in China. Coverage gaps arise from at least two core factors. The first is raw availability—i.e., as noted earlier in the analysis, official Chinese government statistics are incomplete. The second factor is timing—in other words, the National Bureau of Statistics of China discloses oil...
storage data on an episodic and irregular basis, making it only marginally useful to analytical teams tracking a dynamic global crude oil market in which China is an important participant. Indeed, each of the last three official strategic petroleum reserve (SPR) storage volume disclosures by China’s National Bureau of Statistics came more than six months after the report preceding it—an eternity in oil market terms.

Satellite data could also be fused with a broad range of other data points showing oil storage activities, including but not limited to:

- monitoring oil tanker traffic into Chinese ports;
- analyzing drilling locations to gain insights into domestic oil and gas production trends;
- surveying new pipeline construction in order to track infrastructure buildout and identify the path of infrastructure that might otherwise be hidden behind state secrets laws;
- tracking refinery, petrochemical plant, and pipeline pump station activity levels via infrared imagery;
- expanding existing data sets on refinery runs and production of gasoline, diesel fuel, and other refined products; and
- calculating vehicle densities and flow patterns on roads in major gasoline consumption centers and highway corridors.

TO WHAT EXTENT COULD SATELLITE OBSERVATION OF CHINA’S OIL AND GAS SECTOR BE VULNERABLE TO “SPOOFING”?

If China’s government is indeed committed to the idea that a substantial portion of the country’s oil and gas sector data be protected as state secrets, this raises the question of to what extent Beijing might work to make satellite observation of its energy industry more difficult. Large-scale deception has historically fallen primarily
within the military domain. Consider the army of decoys “commanded” by General George Patton to convince Hitler that the Allies would invade France near Calais, rather than at Normandy.\footnote{13}

Accordingly, multiple interesting questions arise as to whether the Chinese government would consider deploying large-scale countermeasures to foil satellite data collection. This would involve significant capability and cost dimensions. There might also be legal ramifications if countermeasures taken by firms like CNPC or Sinopec, who have publicly traded subsidiaries, led satellite intelligence firms to inadvertently report incorrect data that misled shareholders.

On the capability front, oil storage tracking that relies on assessing the shadows cast by floating tank roofs might be spoofed by painting those roofs in patterns that disrupt algorithmic analysis.\footnote{14} Other types of earth observation platforms that use synthetic aperture radar (SAR) and can measure actual movement could defeat spoofing measures aimed at countering shadow–based visual observation. For instance, Finnish company ICEYE has launched the world’s first microsatellite to provide SAR imaging, offering 10–meter resolution at a price of “lower than $1 per square kilometer.”\footnote{15}

Value–add analytical services—including some that offer energy sector–focused products such as Ursa Space Systems—are also working to commercialize growing SAR data sets.\footnote{16} Over the past several years, the cost of visible satellite imagery has fallen significantly while the output has simultaneously increased in quality. If the same trends unfold in the SAR space, such imagery is likely to become a more widely used analytical feedstock for commercial and academic actors alike.

But even radar–based observation has limits. Future oil storage facilities in China might either be built underground or designed to use fixed–roof tanks that are impervious to analytical methods predicated on measuring tank level movements. If China decided to make its oil storage facilities less visible from space, it would have a number of options at its disposal, at a range of price points.

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**FIGURE 2 — CHINA’S OIL DATA SECRECY BECOMING UNTENABLE IN THE SATELLITE AGE**

So how much might China’s oil companies have to potentially spend to hinder satellite data collection, and how would that intersect with their commercial and fiscal realities?

Fixed–roof tanks can cost between 10 and 20 percent more than comparable floating roof tanks.\footnote{17} A leading tank roof vendor indicated that adding an aluminum geodesic dome roof to a 300–foot diameter crude oil storage tank would likely cost between $1 million and $1.2 million per tank.\footnote{18} In practical terms, this means that the price tag to conceal the floating roofs of the 52 tanks at the original Zhoushan SPR site near Shanghai alone could approach $60 million. The facility, which came fully online in June 2007, originally cost approximately $50 million to build.\footnote{19}

The costs of installing fixed–roof tanks nationwide could easily climb into the billions of dollars, especially because...
the scale of demand in China for such services under such a scenario would likely overwhelm the global vendor pool. High costs could in turn forestall broad adoption of fixed roofs by China’s oil and gas industry, a commodity-based business in which cost control is immensely important, state-controlled enterprises must still generally strive to maintain a high degree of commercial competitiveness, and the sheer scale of the energy system could make spoofing measures too costly to broadly deploy. Accordingly, we would be surprised if companies would accept the burden of significant retrofit costs without large state subsidies and/or serious political pressure. That said, the more likely outcomes moving forward could be that:

1. an increasing proportion of new oil storage tanks in China will be built with fixed roofs that hinder visual and radar-based remote analysis (with the beneficial side effect of eliminating rainwater accumulations atop tank roofs); and
2. more storage—especially at SPR sites—will be built in underground mined caverns.

To date, China has completed at least one subterranean SPR site and has several more under construction. Oil storage operators in the country have strong incentives to go underground from both physical security and economic perspectives. Data from sources in South Korea suggest that mined caverns for underground crude oil storage can be built for more than 60% less—per barrel of capacity—than above-ground tanks. Yet the substantial sums of capital China’s oil storage providers have sunk into floating roof tanks, often designed with multi–decade service lives, means they will likely be very reluctant to prematurely phase out such infrastructure unless forced to by government mandate. Accordingly, a material portion of China’s oil storage capacity likely will remain susceptible to space surveillance for many years to come.

**FIGURE 3 — POTENTIAL ANNUAL COSTS OF OBTAINING SATELLITE DATA OF KEY OIL STORAGE POINTS IN CHINA**

<table>
<thead>
<tr>
<th>Surface area</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Known China oil refineries in data set</td>
<td>193</td>
</tr>
<tr>
<td>Known China oil storage depots in data set</td>
<td>278</td>
</tr>
<tr>
<td><strong>Total surface area of satellite view to observe (km²)</strong></td>
<td>76,228</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Imagery costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial basemap acquisition</td>
<td>Free</td>
</tr>
<tr>
<td>Monthly high-resolution tasking @ $5/km²</td>
<td>$4,573,680</td>
</tr>
<tr>
<td>Monthly medium-resolution tasking @ $2/km²</td>
<td>$1,829,472</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total estimated annual cost</th>
<th>Monthly updates</th>
<th>Quarterly updates</th>
</tr>
</thead>
<tbody>
<tr>
<td>High resolution images</td>
<td>$4,573,680</td>
<td>$1,143,420</td>
</tr>
<tr>
<td>Medium resolution images</td>
<td>$1,829,472</td>
<td>$457,368</td>
</tr>
</tbody>
</table>

**NOTES** Total surface area calculation assumes a 5 km buffer around each storage facility and a 10 km buffer for each refinery, with the overlapping area dissolved.

**SOURCES** Bloomberg, China Petroleum Map 2012, LandInfo, authors’ analysis

**HOW MUCH MIGHT THIS SATELLITE DATA COST?**

Satellite data acquisition costs are a huge concern, particularly for budget–constrained academic and public policy researchers. Below, we price out two fundamental pathways: (1) the acquisition of “refined” China oil sector data directly from an “analytics as a service” vendor, and (2) the acquisition of “raw” satellite imagery that consortium members could then run through their own analytical processes.

Each path has its pros and cons. The biggest pro for acquiring already processed, ready–to–use data is that the project could launch very rapidly. Conversely, this benefit illustrates its corollary. Namely, a core challenge of the bootstrap, raw imagery approach is the significant upfront fixed cost of time and human brain energy necessary to acquire dedicated computing infrastructure and devise algorithms for image analysis, among other steps.
Another fundamental challenge stems from the fact that “analysis as a service” vendors might be wary of providing much data to a forum whose core goal is to provide regularly updated, detailed China oil data to the broader public for a nominal cost, or perhaps even free of charge. High-paying commercial customers might balk at such broad data publication even if a time embargo was placed on the forum’s ability to use the data in open-access applications. Data independence concerns might ultimately make the bootstrap approach the best aligned with the venture’s overall goals.

Some very rough cost estimates suggest that an academic venture to seriously assess China’s oil sector on a monthly basis could be prohibitively expensive at present, even assuming that imagery vendors gave participants a 50% discount from posted commercial satellite imagery rates (which some vendors, such as Airbus, are willing to provide). A simple model suggests that obtaining monthly high-resolution satellite views of China’s key oil storage infrastructure points (refineries and stand-alone crude oil and refined product tank terminals) could cost roughly $4.5 million per year, or about $1.1 million per year if monitoring were done quarterly (Figure 3). Note that expanding the area of image capture to include drilling sites would significantly increase the costs from the levels shown in Figure 3. The cost levels indicated in these simple models suggest that the participation of the EIA and IEA, and their well-funded data acquisition programs, might be instrumental to the success of a venture aimed at using satellite data to create a “shadow EIA” for China’s energy sector.

The cost estimates in Figure 3 were derived by:

1. Compiling a detailed list of all of the oil refineries in China available through the Bloomberg Professional Service, as well as a list of oil storage infrastructure assets obtained via China Petroleum Map 2012.
2. Following up the initial compilation with a deep online search in Chinese for facility level data—such as capacity, operator, and coordinates—as well as additional refinery and oil storage assets to establish a comprehensive China oil infrastructure database.
3. Creating separate shapefile layers in QGIS for the refineries and oil storage facilities (Figure 4).
4. Dissolving the layers and running a buffer analysis for each one to determine how many square kilometers of surface area would need to be covered by satellite imagery in order to capture the oil storage infrastructure associated with a point in the shapefile (typically intended to lie at the centermost part of any given point). The buffer for refineries was 10 km from the center point and 5 km from oil storage facilities. There was some overlap between facilities in certain cases that constitute a small subset of the total sample, but the dissolve function counteracts the risk that a given piece of surface area could be “double counted.”
5. Adding up the total area from the respective layers (76,228 km²) and multiplying it by $5 per km² for high-resolution imagery and $2 per km² for medium-resolution imagery to obtain the cost of a single satellite “run” covering the area of interest. These numbers were based on a satellite imagery pricing list provided by LandInfo, which notes that at least one of its imagery providers grants discounts of up to 50% for academic users.
6. Multiplying the per run costs by 12 to derive the annual cost of performing monthly observations and by four to derive the annual cost of quarterly observations. Our model assumes that the initial “basemap” imagery can be obtained through archival imagery from NASA, the European Space Agency, and other openly accessible data sources.

Given these high costs, partnering with satellite owners to obtain even more highly discounted (or possibly free) imagery would be an enormously helpful financial catalyst for this proposed China oil forum project. At least one possible model currently exists. Satellite imaging company Planet
has established a program to provide limited amounts of imagery to academic researchers, with a free “Basic” license conferring the right to download 120,000 km² of imagery per year, an “Investigator” license allowing 50 million km² per year at a rate “priced competitively for academic researchers,” and an “Institutional” license providing access to one billion km² per year, for an unspecified rate.²⁶ Note that this is raw imagery and that the person or entity obtaining it must build their own analytical capabilities to process the information into systematically useful data sets.

To put those numbers in an oil analyst perspective, the “Basic” license would allow a researcher to cover all of China’s oil refineries and main storage tank facilities once per year, while an “Investigator” license would allow those areas of interest to be covered daily, with substantial spare bandwidth left over. Since the end products would be used for academic research—not sold—such use would comply with Planet’s permitted usage parameters.

**CONCLUSION**

Ultimately, we hope that creating detailed, reliable, and publicly available models of China’s internal oil flows can provide insights that improve energy and environmental policymaking at a global level—including work by Chinese scholars who would have access to a broad and deep level of data disclosure previously unavailable to them. Perhaps greater transparency created by external...
governmental, NGO, and academic researchers will eventually stimulate the Chinese government to improve its own oil sector data disclosures. Only time will tell, but the research potential of the satellite-based, open source China oil data concept is substantial. Analytical dividends could flow for years from investment in the project by government agencies, academic institutions, and private philanthropists interested in China--focused energy and environmental issues.

ENDNOTES

2. See http://tankertrackers.com/”.
4. Ibid.
11. Copies of SPR volume disclosures on file with the authors.

We hope that creating detailed, reliable, and publicly available models of China’s internal oil flows can provide insights that improve energy and environmental policymaking at a global level—including work by Chinese scholars who would have access to a broad and deep level of data disclosure previously unavailable to them.


24. Data were predominantly extracted from the press releases of state-owned oil companies, i.e., Sinopec, PetroChina, and CNOOC. Other data sources include but not limited to: INFOPETRO (http://www.info-petro.com.cn/), 百度百科 (https://baike.baidu.com/), 互動百科 (http://www.baike.com/), and individual refining/storage companies’ websites.