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A natural-gas flare at a refinery in Corpus Christi, Texas.

We commercialized a methane capture technology in ten years — here's how

Guoping Hu, Eric F. May & Kevin Gang Li

Lessons from launching a spin-off company: invest in collaborations and engineering, and protect intellectual property to speed up tech development.

Methane accounts for 16–20% of global greenhouse-gas emissions, and is more potent at trapping heat in the atmosphere than carbon dioxide (see *Nature* **596**, 461; 2021). More than half of methane emissions come from human activities, including leaks from refineries, coal mines and landfill sites. We developed a material that removes methane from streams of mixed waste gases (see, for example, ref. 1).

Commercializing our material took ten years: from developing it in a chemistry laboratory (2011–18), to proving its effectiveness in a coal-mine gas plant (2018–21), to manufacturing and beginning to sell it (2019–21).

That sounds like a long time, but it's actually fast. In our field of industrial chemistry, it often takes up to 20 years to get a product out of the lab and on to the market. Most prototypes fail at the first hurdle – getting industry backing. Patents last for only 20 years, making it a race against time.

The world needs new technologies urgently to avert climate change. Unfortunately, there's little guidance to help academics on the commercialization journey and through unfamiliar territory in the corporate and legal worlds, while juggling university career requirements along the way.

To spur others on, we share here our lessons for speeding up technology translation. Beyond an exciting product, it needs time, money, business management and collaboration across many sectors. Clear identification of the market position of the product, strategic collaboration with key partners, and access to excellent manufacturing and engineering capabilities make a new technology more likely to cross the finish line.

Identify the product

Start with the '5W' questions: what is the product, who are the customers, what are the competing technologies, what is the product's economic value and what are its social and environmental impacts. The answers will direct you to the right industries, sources of finance and marketing messages. Address any problems raised in parallel.

Our product is a new type of adsorbent material (ionic liquidic zeolites; ILZs)[1] that captures methane efficiently. It gets around a problem that has challenged chemists for decades – separating methane from nitrogen in the air. The two gases have similar molecule sizes, boiling points and reactive characteristics[2].

On discovery, it wasn't obvious how our material would be used. Serendipity played a part. K.G.L. moved jobs in 2012 to study natural-gas processing (with E.F.M.) at the University of Western Australia in Perth. We worked on a project to reduce methane emissions from the vent streams of liquefied natural gas plants. ILZ materials seemed a good fit. And the target customers became clear: liquefied natural gas refineries, coal-gas enrichment plants and landfill sites, as well as renewable-biogas production facilities.

We focused first on customers that would reap the most benefits of trialling our technology for the least cost. Large liquefied natural gas plants were too complex. Chinese coal mines fitted the bill. In 2014, natural gas was cheap and abundant in the West but in great demand in China. And China supplies most of the raw materials for adsorbents. Researchers who commercialized porous catalyst materials called metal–organic frameworks[3] also started by targeting small-scale research institutions rather than large chemical plants.

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Excess methane gas is burnt off at a landfill site.

Next, we needed to face the competition. Methane treatment is a fast-moving field. There are many options for treating low-grade methane mixtures. Each has pros and cons. Lean-burn gas-to-power generators are portable and simple, but have low yields. Catalytic and thermal oxidizers work well on dilute streams of gases but waste heat energy. Activated carbons are cheap but struggle to separate methane and nitrogen. Our ILZs are more selective but we still had to maximize their performance – by controlling particle shape and size to maximize how much ILZ material could fit inside the industrial vessels used to capture the methane.

> **"Cost of production might be high at the outset when there's an immature supply chain."**

Pricing is challenging for any new technology. Ultimately, a price is set by estimating the marginal value a technology can deliver to a customer, relative to conventional options, offset by the risk to the customer of doing something new. Cost of production might be high at the outset when there's an immature supply chain. Direct costs (labour, materials, storage, transport and utilities) and indirect expenses (sales, marketing, financing, tax, depreciation and patenting) must be factored in.

At each step, it's important to listen to what customers, partners and other stakeholders say. The product might not be what the market needs right now; the business model might not be profitable. In our case, we sold advanced engineering solutions alongside the materials as a package to add profit – similar to how printer manufacturers make extra money by selling ink cartridges.

Environmental impacts must be considered, such as material toxicity, waste management and carbon footprints. Our materials can be used for 8–20 years, after which they are heated and recycled or buried. This disposal cost is then weighed against the environmental benefits of using the material. One tonne of ILZ can capture about 40 million tonnes of CO_2-equivalent greenhouse gases over its lifetime.

Answers to the '5W' questions might change during the journey, as the technology and supply chain develop. Gather data to define the answers more precisely. Keep an eye on global shifts, in technology, economies and policy.

Protect intellectual property

A patent confers a legal right to make, use and sell a technology for a period of time, often 20 years (as, for example, in the United States, China and Europe). It excludes others from doing so for that time. Trade secrets are an alternative to patents for protecting intellectual property. That requires you to avoid publicizing key manufacturing steps so that they are hard for others to follow. In practice, a mixture of approaches could be used. We started off relying on trade secrets but deployed multiple patents as we proceeded.

First, narrow down which aspect to patent. It could be a material, its use, a device or a concept. Second, talk to an institutional intellectual property (IP) officer and a patent attorney early on. They will know, for example, whether a product has commercial value, whether it is practical to enforce protection, and whether there are sufficient data to support your claims.

We lodged our first provisional patent application in Australia in 2015. That stage requires only a solid proof-of-concept. Accurate wording is crucial. Start with broad claims, provide specifics to prove inventiveness and disclose as little as possible on specific techniques.

A patent is important for setting up a spin-off company. Albeit intangible, it is the company's initial asset and it attracts collaborators and investors. The security offered by our patent enabled us to disclose our recipe to collaborators, which was crucial for scaling up our product's manufacture.

However, the patent process is lengthy and expensive. It took us between four and seven years from applying for the international patent in Australia (2015), to the award of the first full patents in national territories, in the United States (2019), China and Australia (2021). We invested more than Aus$20, 000 (roughly US$15,000) to secure the US patent alone and each patent has an annual fee, as well as the continuing costs for a patent attorney. That's a lot of money for a spin-off. We targeted the countries most likely to provide big markets. And we lodged more patents as the product developed and as other candidates emerged.

That's a long time for any researcher to spend working on a project in the shadows. Most academics, including us, feel conflicted about limiting access to their work. Openness is key for scientific progress. And researchers need publications to get jobs, grants and promotions. For us, that meant walking a narrow line. We chose to publish journal articles on advanced uses of our material[4], rather than disclose sensitive information about its manufacture. Later on, we were able to say more by citing patents[5].

Secure funding and partnerships

It takes millions of dollars to move a technology such as ours through the three stages of research and development: laboratory research, industrial demonstration and commercial-plant trials.

The first step, research, is familiar. To develop the material in the lab, we initially received grants totalling a few million dollars from the Australian Research Council (ARC), Western Australia's state government and global energy companies. Cross-collaboration with E.F.M.'s group opened up lines of funding for industrial transformation from the ARC. These enabled us to scale up the production of our material to kilograms, build apparatus and test the performances of adsorbents and cycles for methane capture.

This stage is where most projects stall. Once the research funding was depleted, we too almost wrapped up the work. Fortunately, the promise of our material urged us on.

Accessing funds beyond research grants requires building partnerships with industry and other specialist groups. These might range from chemical, mechanical and electrical engineers to business managers, economists, legal consultants and accountants. It's these interconnections that eventually allow efforts to snowball. Here are some tips.

> "A patent is important for setting up a spin-off company."

First, seek strategic partnerships as soon as the product is identified. These might not necessarily be with the big players. We had little luck when we approached large adsorbent and gas-separation companies. But we did get attention when we reached out to small-to-medium enterprises, which were more willing to take risks.

Second, forge international links. These open up funding channels, areas of expertise and markets. Conferences and exhibitions are good places to connect. For example, during a meeting on methane abatement from coal beds, we initiated a collaboration with a Chinese gas-separation company. We agreed to conduct tests while the terms and conditions were being negotiated. We protected our IP through a non-disclosure agreement and by keeping trade secrets while building mutual trust. Such careful steps avoid future business disputes.

Third, access grants for boosting collaborations. In 2017, we were fortunate to receive Aus$2 million (in direct and in-kind support) through the Australian government's Global Innovation Linkages Program. Those links brought three organizations together to establish a start-up company called Gas Capture Technologies.

Finally, find collaborators wherever conditions are most favourable. For example, we benefited from working with partners in Australia for IP generation, a German manufacturer who supplied specialized raw materials, and gas companies in China for processing and commercial demonstration.

Engage engineers

Good engineering is crucial. Working closely with production engineers can speed things up. For example, working alongside the Chinese manufacturer, it took us two years and many iterations to find a commercially viable recipe for our material (see go.nature.com/3j3tatb). Along the way, we developed a engineering cycle[6] that allowed us to double our methane-capture efficiency and cut capital costs. Using established facilities, engineers and supporting teams is also faster and cheaper than starting from scratch.

The next step, commercial-plant trials, required us to find an organization that stood to gain from and that was willing to test the technology. After many site visits, workshops and feasibility studies, one of the leading coal-bed methane-gas companies agreed to support us to build our first commercial methane-recovery plant at the Qinshui Basin in Shanxi province, China. It was a small plant in one of the world's largest regions of coal-bed methane reserves. Our team spent five months on site to install, commission and test the plant.

Success won sales orders from customers in North America and Europe, on the basis of information on our website and published papers. We were able to use the Chinese partner's plant to manufacture materials at scale and treat waste. Using others' facilities reduced the time for upscaling by two to three years.

Communicate effectively

Miscommunication is probably the biggest cause of commercialization delays. Misunderstandings waste time and money and cause tensions and delays. Good communication builds trust. Broad teams (accountants, engineers, scientists and sales people) are necessary to be successful but are not all on the same page. A balance needs to be found to engage the whole team, to keep everyone in harmony and to split up specialized work to sub-groups for efficiency. Language and cultural barriers can be an issue in international collaborations, and appointing personnel able to work across different cultural backgrounds was a crucial step.

Communications across disciplines was also key. For example, before constructing a demonstration plant, we ran through every piece of equipment in our piping and

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The methane-capture plant at Qinshui Basin in Shanxi, China, uses the technology developed by Guoping Hu, Eric May and Kevin Gang Li.

instrumentation diagram at least 20 times with the design, mechanical and electrical engineers involved. And we continued to speak to them through the entire process. When the local rainy season interrupted progress, they helped us to get back on course swiftly, for example by improving the instrumentation's water resistance.

What next

More hard work lies ahead — increasing productivity, securing capital and building a robust supply chain. We need to diversify products and revenue streams and hire talented people, who can work full time. For us, it's been a second job alongside academia. Had we known what lay ahead, we might have reached commercial scale even faster by working full time.

If we had the same opportunity again, we'd establish our spin-off sooner, engage with industry more frequently, get more feedback at industry sessions in conferences or exhibitions and put our technology into a commercial environment earlier. We might have applied for patents separately in different countries rather than go through the slow international process.

We call on IP authorities to speed up the patent examination process, communicate more effectively with other jurisdictions, and avoid duplicating patent searches and queries.

Government and institutional support for commercialization is crucial. Long-term

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support for innovation hubs or parks needs to be sustained. And funding and training should be more systematic and widely available. Training in IP protection and commercialization should be readily available to researchers, from tutors with experiences in the business world and entrepreneurs who are involved in commercialization themselves. Directors' courses, and training in governance and business would also help.

Lastly, we encourage lab researchers who are feeling entrepreneurial to embrace the journey, with patience, perseverance and a proactive approach.

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The authors declare competing interests; see go.nature.com/3xauaIg for details.