science & technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

2019 – Year of the Periodic Table of Chemical Elements

THE PERIODIC TABLE IS A WINDOW INTO THE UNIVERSE

National Science and Technology Forum

The Periodic Table of Elements is a lens through which to look at our world

- a message from Jansie Niehaus, NSTF Executive Director

DECLARING 2019 'International Year of the Periodic Table' the United Nations General Assembly described it as "one of the most significant achievements in science and a uniting scientific concept, with broad implications in Astronomy, Chemistry, Physics, Biology and other natural sciences. A unique tool enabling scientists to predict the appearance and properties of matter on Earth and the rest of the universe. Many chemical elements are crucial to enhance the value and performance of products necessary for humankind, our planet and industrial endeavours."

While, at first glance, the table may appear as simply an arranged list of elements used as a tool in chemistry, it is a lens through which to look at our world.

In honour of the UN year, we have thus far facilitated three discussion programmes – 'Rare elements for new technologies', 'Managing elements for health and safety' and 'Chemical elements and sustainable development'. In these discussions almost all the elements of the periodic table received a mention. Some were even discussed at length. Questions like the following were asked:

What elements might be in demand now and in the future for use in 4IR technologies? Does South Africa have significant deposits of such minerals? Might it be feasible to extract these minerals, now or in the future? What challenges have to be overcome to make it feasible?

What are the issues related to essential minerals in human nutrition? Where and how do people suffer nutritional deficiency in terms of minerals? What are the issues related to harmful minerals? Some elements are now known to be fatally harmful. For example: lead and mercury. What should be done to prevent such harm?

Jansie Niehaus NSTF Executive Director

We hope teachers will use this wall chart as a teaching aid and learners can use it at home to study the periodic table and its elements and refer to it while doing homework or assignments. The Let's Look version of The Periodic Table is particularly informative, attractive and information-rich and we are grateful for the company's permission to reprint it.

Ensuring that the wall chart is distributed throughout the country reflects our passionate interest in promoting good education in science, technology, engineering, and mathematics (STEM).

We are acutely aware that in this era of concerns regarding health, nutrition, pollution, drought, and extreme weather, the general public is also hungry for information and the hope that scientists are focussed on identifying threats and developing solutions.

The National Science and Technology Forum (NSTF) is the largest national non-profit stakeholder body for all science, engineering and technology (SET) and innovation organisations in South Africa. It represents more than 100 organisations. It has a mandate to engage with government policy and plays a powerful role in consultation on policy matters. In partnership with South32, the NSTF also makes annual awards to recognise outstanding contributions to SET and innovation.

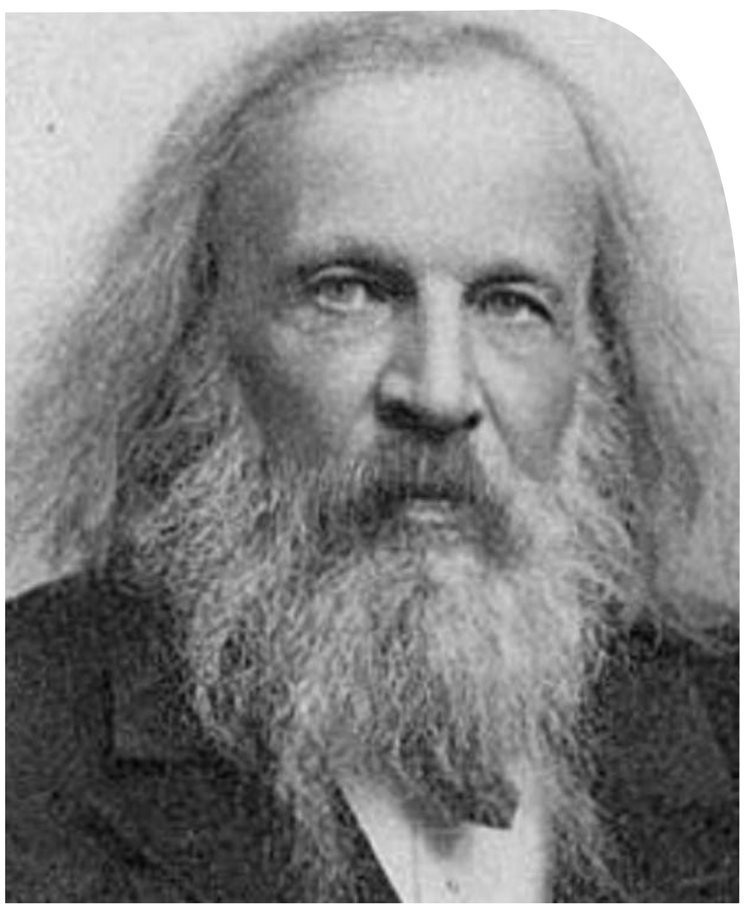
The NSTF provides neutral collaborative platforms where issues and sectors meet. One of its functions is to hold discussion forums, bringing the private and public sector together to address important issues and engage with government policy.

So much more than earth, wind, water and fire

THERE was a time when earth, wind, water and fire were known as the only elements. Modern elements are known by the structure of their atoms. This is so complex that we need a chart with rows and columns reflecting their properties and how they interact with one another. By the 19th century, several scientists were developing a periodic table arranging them according to their atomic weight but Russian chemistry professor Dmitri Mendeleev is credited with developing the first real table in 1869. He organised the 63 elements known at the time into groups with similar properties and left some spaces blank for those yet to be proved.

As award winning science editor Tom Siegfried commented earlier this year, Mendeleev's table looked like an ad hoc chart, but he intended the table to express a deep scientific truth he had uncovered: the periodic law. His law revealed profound familial relationships among the known chemical elements — they exhibited similar properties at regular intervals (or periods) when arranged in order of their atomic weights — and enabled Mendeleev to predict the existence of elements that had not yet been discovered.

"Before the promulgation of this law the chemical elements were mere fragmentary, incidental facts in Nature," Mendeleev declared. "The law of periodicity first enabled us to perceive undiscovered elements at a distance which formerly was inaccessible to chemical vision."



Not even Dmitri Mendeleev, who developed the first real table in 1869, recognised the magnitude of his discovery

His table did more than foretell the existence of new elements. It validated the then-controversial belief in the reality of atoms. It hinted at the existence of subatomic structure and anticipated the mathematical apparatus underlying the rules governing matter that eventually revealed itself in quantum theory. His table finished the transformation of chemical science from the medieval magical mysticism of alchemy to the realm of modern scientific rigor. The periodic table symbolises not merely the constituents of matter, but the logical cogency and principled rationality of all science.

Research continued and in 1913 physicist Henry Moseley proved that the order was dependent not on atomic weight but on the number of protons in an atom's nucleus.

After uranium (element 92) most elements are artificially made and, while the search is still on for undiscovered stable elements, no one knows if there is an end point to the table or if additional artificially engineered elements will expand it even further.

Writing for Jstor Daily (January 2019) neuroscientist Dr Sophie Fessl says, until December 2015, there were holes in the periodic table, elements synthesised but not yet officially recognised. Then the International Union of Pure and Applied Chemistry officially confirmed elements 113, 115, 117, and 118 - nihonium, moscovium, tennessine, and oganesson. Efforts to confirm elements 119 and 120 are underway.

Today the periodic table of elements is regarded as a "stalwart symbol" of chemistry, the chemist Eric R. Scerri enthused. "It graces the walls of lecture halls and laboratories of all types, from universities to industry," he wrote in American Scientist. "It is one of the most powerful icons of science. It captures the essence of chemistry in one elegant pattern."

Yet in the beginning not even Mendeleev recognised the magnitude of his discovery.

Focus of the NSTF discussion forums

AMONG the critical problems that South Africa faces is the demise of mining as a reliable economic sector, in the context of the 4th Industrial Revolution. Further job losses are inevitable and there is a scramble to catch up with the technologies and opportunities offered by this new era. At the same time, South Africa is a country blessed with substantial mineral resources. It is generally recognised that these resources have to be beneficiated and not just exported to other countries. Creating products and industrialisation are the key to our economic future.

South Africa is blessed with substantial mineral resources.

Electronic hardware contains small amounts of a variety of metals as essential components. As the industry continues to grow at an exponential pace, and 4IR technologies all rely on electronics, it is anticipated that these metals will become increasingly hard to access.

There are other urgent issues that lie at the foundation of creating a better future. Prominent, and urgent, among them are education, health and food security. According to the Food and Agriculture Organisation (FAO) food security is not only about the quantity of food available, but also whether people are getting the nutrition required.

Scope and structure

To narrow down the wealth of possible topics and information related to the periodic table, a selection of topics that are relevant to society and the economy were made. The NSTF provided a platform to discuss the following topics over three days:

1. 'Rare elements for newtechnologies',
2. 'Managing elements for health and safety' and 3. 'Chemical elements and sustainable development.' The latter was held in partnership with the Department of Science and Technology (DST) and Dow Southern Africa (Pty) Ltd.

The aim was to include as many elements in the Periodic Table as possible – in celebration of the United Nations International Year. As experts shared their knowledge and views about some of the critical and complex global problems of our time, important issues emerged. There were two organising frameworks – the Periodic Table of Chemical Elements and the 17 SDGs. However, the real discussion emerged from linkages between these, and relating them to contexts where critical problems need to be solved.

Further reading

The top 10 metals powering your mobile: http://www.austmine.com.au/News/category/articles-editorials/the-top-10-metals-and-minerals-powering-your-mobile-phone

https://www.mining-forschools.co.za/lets-explore/parent-and-teacher-guide

https://www.mining-technology.com/features/featurethe-11-most-dangerous-minerals-4256873/

What is the Department of Science and Technology (DST) and the rest of government doing?

THE presentation by Dr Mahlori Mashimbye of DST was called 'Harnessing the South African Chemical Sector for contribution to Sustainable Development Goals'. He is the Director: Chemical and Related Industries at DST. The National System of Innovation can support the SDGs by: Generating data for monitoring, planning, and tracking for informed decisions; promoting the generation of knowledge and analysis for policy, planning, and delivery; assisting in developing and localising technological solutions; and promoting the demonstration, testing, and diffusion of technological solutions.

The DST and the National Research Foundation (NRF) have launched specific initiatives and are aiming to drive global and national partnerships. Dr Mashimbye says that there are, primarily, two approaches for the chemical sector regarding the SDGs: remediation (ie regulating, including banning and restricting use) and R&D and industrial development of alternatives (eg new environmentally-friendly chemical products).

2019 – Year of the Periodic Table of Chemical Elements

THE PERIODIC TABLE IS A WINDOW INTO THE UNIVERSE

science & technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

National Science and Technology Forum

Chemistry, its practice and its teaching

PROF John Bradley, an Honorary Professor: University of the Witwatersrand, presented on 'From Chemistry's Big Bang to One-World Chemistry – a story for chemical education', saying; "Chemistry cannot be separated from the context in which it is conducted and its practice must be considered in relation to its impacts on many interconnected systems."

This includes a focus on sustainability. One-world chemistry looks at embedding in chemistry education a growing awareness of the ways that chemistry interconnects with other disciplines and its application in context. Prof Bradley notes that teaching and practice need to be informed by systems thinking, including embracing multi-disciplinary and cross-disciplinary approaches.

From agriculture, medicines, and plastics to electrical power and ICTs, chemistry has contributed to development across the globe. However, all this has come with consequences.

He points to recent examples, such as the nine million people killed by pollution in a year, a statistic from the UN Environment Programme's 'Global Environmental Report 2019'. The report further notes: "Modern society is living in the most chemical-intensive era in human history: the pace of production of new chemicals largely surpasses the capacity to fully assess their potential adverse impacts on human health and ecosystems."

Systems thinking considers the "component parts of a system will act differently when isolated from the system's environment or other parts of the system". It's a holistic approach that expands the way we think about things. It explores inter-relationships, connections, influences, and multiple perspectives and it will take an extremely comprehensive systems thinking approach to tackle the SDGs which address the intractable problems of our times.

This needs international and national leadership. Systems thinking moves beyond events, into patterns and trends, system structure and drivers, and then predominant social paradigms (mental models and world views). This is known as 'The Iceberg Model of Systems Thinking' by Michael Goodman.

Prof Bradley says, "The crisis of sustainability, the fit between humanity and its habitat, is manifest in varying ways and degrees everywhere on Earth… Sustainability is about the terms and conditions of human survival, and yet, we still educate at all levels as if no such crisis existed." [ACS Sustainable Chemistry and Engineering, 2014]

Chemistry – the "central-science" must become a "central-sustainability science". Both teaching and practice must be informed by systems thinking and consequently embrace approaches that cross disciplinary boundaries.

(One-world chemistry and systems thinking: Matlin, Mehta, Hopf & Krief IOCD, 2016)

From the earliest stages of science education, the unity of scientific principles and thought processes should be stressed. There should be a growing awareness of the ways that chemistry interconnects with other disciplines.
[IOCD website]

Dr Mahlori Mashimbye of the DST recommended: Encourage educational institutions and academia to introduce a green chemistry curriculum and to do research in green chemistry. Supporting such an initiative can contribute towards attaining the SDGs.

NSTF's vision: A transformed country where science, engineering and technology (SET) and innovation contribute to a high quality of life for all who live in South Africa, where the profile of SET professionals is representative of the population profile and where the education system is effective, particularly in terms of performance in SET subjects and promoting innovation.

What are rare earth elements?

ON the periodic table Rare Earth Elements (REEs), all of them metals, range from the atomic numbers 57 to 71. They are the 15 lanthanide series elements, plus yttrium. Scandium is found in most REE deposits and is sometimes classified as a REE. (Source: Geology.com)

Dr Leon Kruger, who manages Mintek's Hydrometallurgy Division, says REEs are found across the globe but in relatively low concentrations and they are very difficult to separate. Hence the reference to rare.

Mr Sietse van der Woude, Senior Executive: Modernisation and Safety at the Minerals Council, points to some 40 elements in phones that are mined and adds, "When you look at the periodic table, it is easier to say what's not relevant to 4IR because so many elements are.'

Green energy technology needs even more elements and, as the need for them rises, so will the demand for rare metals. South Africa's mineral resources for 4IR rank within the top 10 in the world, except for iron ore.

Addressing titanium, Dr Annelize Botes, Principal Researcher: Materials Science and Manufacturing at the CSIR, says it is considered rare because it is so difficult to produce. It is used in many industries, including aerospace, automotive and medical. They also form part of a larger eco system and she advocates more work with design engineers as they mostly work with steel.

Dr Mesfin Kebede, Principal Researcher at CSIR focused on lithium ion batteries (LIBs), revealing high availability of manganese and titanium for electric vehicles and renewable battery storage.

Van der Woude notes that mining's future lies in new deposits of 'exotics' like REEs and speaks of the impact 4IR will have on industry, with accelerated digitisation heralding exciting changes. There is growing understanding of the importance of good governance in the mining sector, which is a cornerstone of our economy. And, with China producing more than 80 percent of the global REEs, the world is looking for alternative sources.


Mr Sietse van der Woude, Senior Executive: Modernisation and Safety, Minerals Council South Africa

Prof Renee Street, Specialist Scientist, Environment & Health Research Unit, South African Medical Research Council


Mr Sahlulele Luzipo, Chairperson, Parliamentary Portfolio Committee on Mineral Resources

Prof Paul Nex, Associate Professor, Wits


Mr Harry Dube, Technical Advisor, Scientific Production: Agriculture Inputs Control, DAFF

Mrs Nathalie Mat, Nathalie Mat Dieticians

In everyone's interest

IT would be a huge mistake to consider the Periodic Table a tool for science boffins only. It can be applied to every aspect of our lives from the electronics we are so hooked on to the UN's Sustainable Development Goals, to the sea water we surf in, our food security and the 4th Industrial Revolution.

NSTF held three discussion forums this year to unpack issues related to minerals. Executive director of NSTF Jansie Niehaus, reveals, "We used the Periodic Table as a window through which to see minerals and materials in relation to new technologies, mining, nutrition, safety from poisonous minerals, energy, water, food security, and education.

"The Sustainable Development Goals (SDGs) were then placed in the mix as an additional lens through which to see critical issues. The knowledge that was shared ranged from well-established facts and practices, to cutting-edge technological research and ideas.

Minerals and Water

Projections from the Department of Water and Sanitation show that water use is higher than water availability and the gap will increase. As noted by Prof Edward Nxumalo, ours is the 30th driest country in the world. It's also recently had the worst drought in 23 years. South Africa relies heavily on mining activities. If not properly managed, the generated waste poses significant environmental challenges and hazards to human health. At the same time, agriculture, and chemicals industries are producing new types of pollutants. Prof Nxumalo, an Associate Professor at Unisa, presented on 'The Interlink between the Periodic Table and Water Treatment: A Nano Perspective'.

He says South Africa needs to recognise that current water treatment processes are not designed to deal with emerging contaminants, such as ibuprofen and paracetamol. Part of his research deals with using membrane science for drinking, sea water, and wastewater purification. He noted that there are a number of potential nanotechnology applications for water treatment. These include: membranes and membrane processes, photocatalysis, and disinfection and microbial control. Emerging contaminants can be tackled with these advanced techniques.

Prof Lesley Petrik, an NSTF award winner, leads the Environmental Nano Science Research Group at the University of Western Cape, which is known for research on water chemistry and effluent remediation. This includes treating and removing organics and inorganics from industrial brine, acid mine drainage, and textile waste water. Another outstanding contribution is the development of processes for industrial waste reuse.

"The aim is to gain a deeper understanding of waste water chemistry in order to treat it successfully," Prof Petrik explains. "Our studies aim to provide valuable knowledge for the intelligent design and application of new water treatment process."

She and other researchers have long warned of the probable public health risk posed by the planned desalination plants in Cape Town. The biggest problem, according to Petrik, is that our national water guidelines do not require statutory testing for persistent pollutants."

The safety standards set by the national water department do not require testing for harmful organisms in the desalinated sea water, which means the presence of E. coli and Staphylococcus aureus is technically lawful. E. coli is known to cause food poisoning, and staph infections can lead to boils and oozing blisters.

She warns, "So the city can claim the water is within specifications but would not have proved the water is adequately purified from persistent chemical compounds if they did not test for pharmaceuticals, pesticides and disinfectants that are being dumped into the ocean with the sewerage released through the marine outfalls.

Sources of persistent pollutants include pharmaceuticals (eg medications) and there are also pesticides and personal care products, like disinfectants and fragrances. Chemists don't design obsolescence in chemicals. Now add that to the radically increased consumption of chemicals in the last few years. "This is far more of a problem than plastics", says Prof Petrik.

Food security – crop production

Consider chemical elements with regards to health and nutrition. This takes us on a journey from soil, agriculture, water and heavy metal exposure through to human nutrition. "Soil is the foundation of nutrition," says Mr Ramakgwale Mampholo, Deputy Director: Land Use and Soil Management, Department of Agriculture, Forestry and Fisheries (DAFF).

Mampholo explained that soil is a national asset. He presented on 'The nexus of soil minerals, plant and human health' and emphasised that all stakeholders need to understand that good nutrition starts with healthy soils. Soil mineral status affects food production which, in turn, affects food quality ie nutritional value and safety.

The use of fertilisers comes with a risk of heavy metal accumulation in soils, says Harry Dube, Technical Advisor, Scientific Production: Agriculture Inputs Control. He spoke on 'Important minerals in agriculture: beneficial and contaminants'. Pollution of heavy metals, such as arsenic, cadmium, copper, nickel and selenium, can lead to the accumulation of toxic levels in the human body.

Responding to the fertiliser and food challenge, the way agriculture has been practised has contributed extensively to soils lacking in vital nutrients and this affects crop yields. Consequently, fertilisers are essential. Harry Dube noted that there are five main plant nutrients – with three that are absolutely critical for humankind's survival: nitrogen (N), phosphorus (P), and potassium (K). Without the industrial production of nitrogen, agricultural production would not have been possible at its current scale. However, we need to relook at the use of nitrogen fertilisers. Most soils in South Africa are acidic (and thus less productive) because of the overuse of these type of fertilisers. Phosphorus is the most deficient in soils in terms of plant nutrition.

Increased phosphorus means increased crop yields. This nutrient is not a renewable resource – it is mined. While South Africa has 10 percent of the world's phosphorus reserves, it exports most of it. Mr Dube notes that this essential mineral needs to be managed carefully. Excessive phosphorus has negative effects including poisoning soils and leaching into water, reducing the quality of the water.

Potassium is a fairly common mineral nutrient in soils. About 2.3 percent of the earth's crust is potassium but it's not evenly distributed. South Africa has none.

To continue food production in a sustainable way, we need to relook at how we use fertilisers and consider organic fertilisers and using conservation agriculture.

Some areas can be rehabilitated for agriculture after mining but not where there are heavy metals. South Africa has a very high nutrient loss in the soil.

Without industrial production of nitrogen agricultural production at current scale would not have been possible. Nitrogen (N) is the most abundant gas in the atmosphere constituting close to 78 percent. However, it is in unavailable form due to the strong triple covalent bonds. It can only be produced industrially (Harber-Bosch process), fixed by legume plants (eg beans) or by lightning. The problem with fertilisers containing nitrogen, is that most soils in South Africa are acidic and rendered less productive due to over usage of nitrogen fertilizers.

Recommendations:

- We need to use more organic fertilizers. Explore the use of more animal manure and human excreta as fertilizers. Develop better regulations to monitor the use of nitrogen fertilizers on farms (nitrogen budgeting); and rotate cereal and legume crops.

Food security – adequate intake of minerals

Ms Nathalie Mat, registered dietitian, presented on 'Mineral elements for health', looking at the main minerals required by the body - calcium (Ca), potassium (K), sodium (Na), and magnesium (Mg); and trace minerals iodine (I), iron (Fe) , and zinc (Zn). All of these minerals are needed by the body for essential functions. However, only small, even minute, amounts are required. An oversupply of these minerals in the body are just as dangerous as a deficiency (undersupply) of the minerals. She notes that the body is made of different systems, all the way down to cells and atoms. In fact, we could see ourselves as a body of chemical reactions.

Minerals to be mined for 4IR technologies

When Prof Paul Nex, Associate Professor: University of the Witwatersrand presented on 'Critical Raw Materials, "Hype Cycles" and the 4th Industrial Revolution (4IR)', he explored context, as well as patterns and trends. He noted that what is considered 'critical' in critical raw metals (CRM) differs across countries, contexts and times: "Any definition depends on the country you are in, the technology / industry you are interested in, your perceived risk of future supply, and perceived demand. All are subject to change."

Certain commodities are seen as critical for the 4IR, but global demand for these go through 'Hype Cycles'. Demand peaks quickly, then drops steeply, and perhaps stabilises at a level in between (or disappears). The prices for such raw materials follow demand. When prices stabilise somewhat, it may no longer be profitable to mine and extract them.

In terms of CRM for South Africa, Prof Nex says it depends on what is envisaged for the next 10, 50 and 100 years. Furthermore, we can't place a value on our raw metals if we don't know what we have. There isn't a great deal of information on Africa's and South Africa's resources and reserves. This can only happen with further exploration. CRMs need to be contextualised to see the larger picture. Part of this is their relation to climate change and green technologies.

As he says, electronic vehicles use four times as much copper (Cu) as our current engines. This means 'green' needs mining. Furthermore, renewable energy requires more raw materials, not less, at least in the short and medium term. It's about understanding the larger system for decision making. We need the materials for 4IR and this means mining. At the same time, we need to develop a carbon free or a low carbon economy to reduce the impact on climate change. A lot that is associated with a low-carbon economy (for example, electronic vehicles, renewable energy sources, and fuel cell energy) are not 'clean' solutions. There needs to be a balance and not an 'either/or' scenario.

According to Wikipedia: "Only gold (Au), silver (Ag), copper (Cu) and the platinum metals occur in nature in large amounts. Over geological time scales, very few metals can resist natural weathering processes like oxidation, which is why generally only the less reactive metals such as gold and platinum are found as native metals." The platinum group metals (PGMs) consist of platinum (Pt), palladium (Pd), iridium (Ir), osmium (Os), rhodium (Rh), and ruthenium (Ru). These six metals are next to each other on the Periodic Table – three in one row, with the other three directly underneath.

Recommendations:

Dr Annelize Botes suggests the following to ensure the supply of raw materials to industry: Expansion and improved efficiency of ore mining or metal extraction; Resource efficiency in production and use; Recycling, ensured by recyclable designs, recirculation strategies and efficient recycling technologies. When developing new technologies, existing options to ensure the supply of raw materials should be an integral part of the basic planning considerations.

Recycling: Recycling will become an increasingly important source of raw materials. E-waste should be collected and the valuable metals (of which there are many) should be separated for re-use. Although each machine (computer, cell phone, etc) contains minute amounts of these, it should be possible to recover them at a scale that would be profitable. Research, development and innovation in this area should be supported.