Recycling Materials to Transform Construction Industry and Address Climate Change

Shrish Patel and Alexander Orlov (Stony Brook University, USA)

Abstract

Concrete is by far the most abundant material produced by humanity in both volume and weight. It is not surprising that it is also a significant source of solid waste that ends up in landfills. Based on EPA data, the Construction and Demolished (C&D) concrete waste accounts for 70% of all the construction materials in landfills. Moreover, cement manufacturing emits approximately 20% of all industrial oxides of nitrogen (NOx)emissions leading to a negative impact on human health and the environment. This report will provide an overview of concrete production, the environmental challenge in the cement industry and put forward a policy recommendation to address climate change using innovative technological approaches.

Air Pollution and its Impact

As per World Health Organization (WHO), an estimated 7 million people are killed worldwide every year due to air pollution [1]. 91% of the world's population lives in places where air pollution levels exceed WHO guideline limits [2]. The ambient and household air pollution attributable death rate is higher in the continents of Asia and Africa, as shown in Figure 1. Among multiple sources of air pollution, the cement industry is potentially the most significant anthropogenic source of air pollution. The industry emissions include oxides of nitrogen (NO_X), oxides of sulfur (SO_X), oxides of carbon (CO, CO_2), and Volatile Organic Compounds (VOCs) [3, 4]. According to various studies, CO_2 emissions from cement manufacture account for 5-7% of global total CO_2 emissions. [5-8]. CO_2 emissions from the cement manufacturing process are mostly caused by two factors: raw materials and fuel combustion. NO_X and SO_X emissions are some of the most serious environmental health and safety issues associated with cement manufacturing [9].

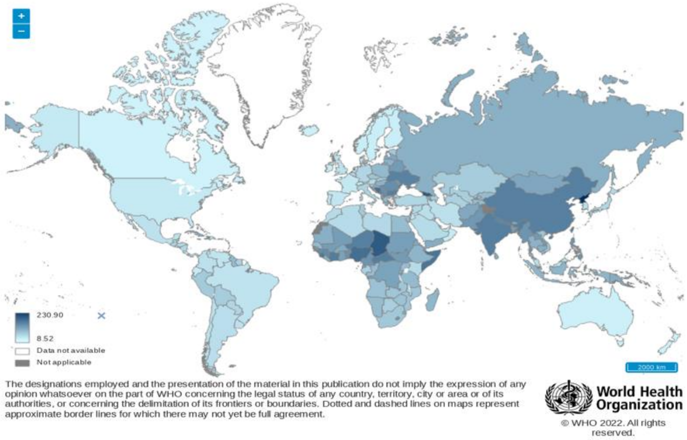
Sulfur oxides are produced by the burning of sulfur-containing fuels and the oxidation of sulfur-containing raw materials [10]. These sulfur oxides combine with water vapor and other compounds in the atmosphere to generate sulfuric acids. These acids dissolve in the suspended water droplets and are carried down into the soil by rain or snow. This is referred to as acid rain. Similar to sulfur oxides, nitrogen oxides are produced in the high-temperature combustion process of a rotary cement kiln. Approximately 90% of nitrogen oxides are produced in the form of nitric oxide (NO), with the remaining 10% produced in the form of nitrogen dioxide (NO_2). At atmospheric conditions, NO transforms to NO_2 at the exit of the stack [11]. NO_X, like sulfur dioxide, interacts with water and other chemicals to form a variety of acidic compounds. NO_X reacts in the atmosphere under exposure to the sun to form ground-level ozone, which causes respiratory illness and other health issues [12-15]. In summary, based on the WHO data, 9 out of 10 people worldwide live in places where air quality excessed the WHO guideline limit. Therefore it is important to address this problem to reduce emissions and prevent hazardous effect to human health and environment.

the COVID-19 pandemic, frontier technologies such as AI showed their usefulness. For example, by adopting AI, Republic of Korea was able to develop much needed diagnostic kits within a month in the. For another example, hospitals in Thailand adopted AI solutions and 5G tech to fight COVID-19. The ubiquitous applications of frontier technologies in Asia and the Pacific have been discussed in ESCAP (2020).

Moving forward, and in the context of 2030 Agenda for Sustainable Development, frontier technological breakthroughs such as AI, robotics, 3D printing, and the Internet of Things amongst others carry the transformative potential. On the other hand, adoption of these technologies is tempered by increasing concerns about the potential negative impacts such as job losses to automation and increased inequalities.

This policy brief examines key opportunities and challenges of frontier technologies in relation to sustainable development. It proposes some key policy priorities that could form the basis of a next generation technology policy framework for the Fourth Industrial Revolution future and ensure that frontier technologies more deliberately align to the ambitions of the Sustainable Development Goals (SDGs).

Figure 1. Ambient and household air pollution attributable death rate (100,000 population)



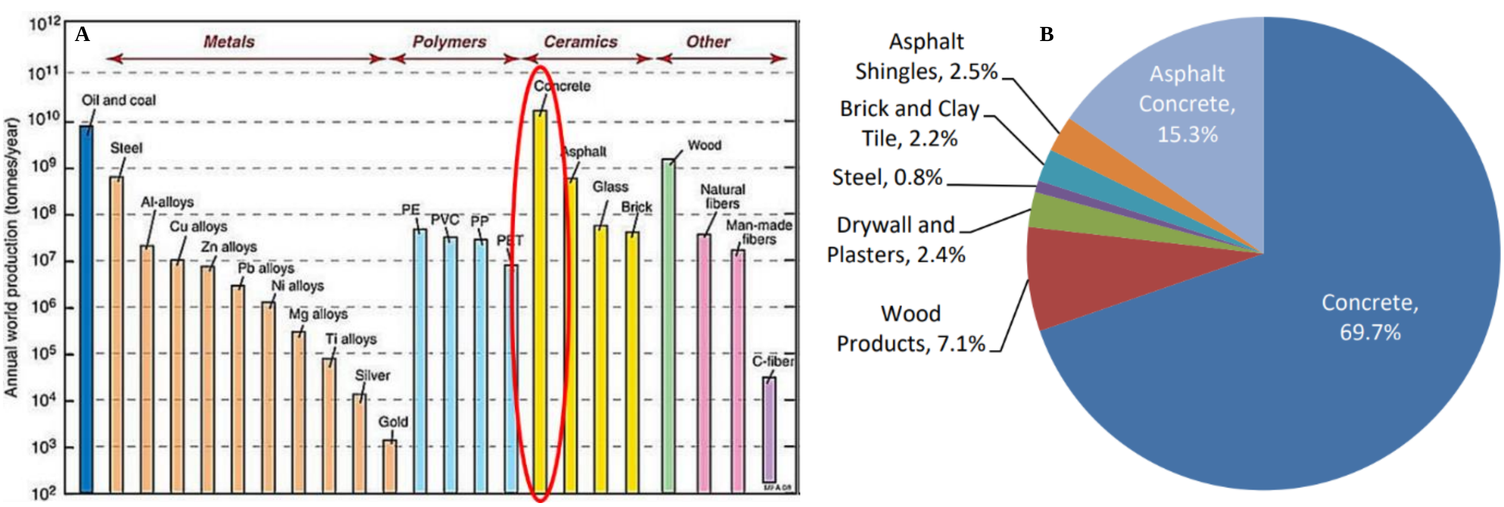
Source: World Health Organization (WHO)

Overview of Concrete Production

As shown in Figure 2(A), concrete is the most widely produced and used building material [16]. The most crucial factor for concrete's success is its superior water resistance [17]. Whereas conventional steel, wood, or other construction materials would corrode and deteriorate, concrete can endure water without degradation. Another reason for concrete's widespread use is its capacity to be molded into a wide range of forms and sizes. When considering both the engineering and economic viewpoints, the most important reason for the widespread usage of concrete is its availability and low cost. The main ingredients for making concrete are a) cement, b) water, and c) aggregates, which are widely available and reasonably priced across the world.

Unsurprisingly, concrete is also a major source of solid waste that ends up in landfills. The worldwide Construction & Demolition (C&D) waste market is estimated to reach USD 34.4 billion by 2026, with C&D waste reaching a rate of 2.2 billion tons per year by 2025 [18, 19]. As shown in Figure 2(B), concrete accounts for up to 70% of total C&D waste [20-23]. One of the primary techniques to solve these difficulties is to recycle old concrete. Thus, in recent years, the worldwide concrete industry is looking towards the reclamation of demolished concrete as a practical and sustainable solution to the scarcity of raw materials and landfill areas. As a result, the use of recycled concrete as a cement replacement material has recently gained more attention as both coarse and fine aggregates from waste concrete can be used to produce new concrete mixtures [24, 25]. In conclusion, it is important to address the large volume of demolition waste from existing concrete structures given the shortage of landfill area, and the rising expense of waste treatment before disposal.

Figure 1. (A) Yearly production of various materials from Ashby (2009) (B) Amount of construction and demolition debris generated in United State 2015 from U.S. Environmental Protection Agency (EPA)



Current Emission Control Methods

There are several strategies to reduce air pollution, which include: (1) overall process modification, where energy efficiency and process parameters are optimized, (2) combustion optimization and control approaches, and (3) introduction of pollution control technologies to remove NO_2. The third strategy utilizes several technological solutions, such as selective catalytic reduction (SCR) and selective noncatalytic reduction (SNCR) [26, 27]. Given that these technologies utilize expensive catalysts and chemicals such as ammonia and urea, the overall cost of implementation of these approaches can be very high. Some studies indicate that the removal of air pollutants can be achieved by photo-catalytically active TiO_2 mixed into cementitious products [28-45]. However, this approach is costly and time-consuming, given the catalyst deactivation, the need to have UV illumination to activate TiO_2, and the overall inefficiency of bulk modification of concrete as the only surface located catalytic particles can be activated by light. Another issue is related to poor dispersibility and/or occlusion of TiO_2 in cementitious materials [35, 46, 47], resulting in poor performance of this modified concrete.

Another strategy for air pollutant removal is based on the utilization of activated charcoal in hardened cement pastes and concrete to enhance the pollutant removal efficacy [32, 48]. Developing new strategies for pollution mitigation is routed in the pressing industrial needs that can be exacerbated by a high probability of even tougher air pollution standards. Overall, the application of air pollution control methods can cut the number of people affected by hazardous air pollutants, however, the cost of the current methods can be prohibitive in developing countries.

Innovative Approach to Simultaneously Recycle Concrete and Address Air Pollution

Utilizing concrete to sequester CO_2 has been a very prolific and promising area of research [1-3]. However, new studies have discovered for the first time how waste crushed concrete can facilitate the sequestration and removal of NO_2 [47] and SO_2 [48]. This innovative approach offers a new way of removing hazardous air pollution from flue-gas in a cheap and sustainable way. This can potentially be a viable way to offset emissions from cement manufacturing factories as well as other industrial installations thereby minimizing their environmental impacts. Moreover, studies show that recycling NO_2 sequestered waste concrete back into the new concrete mixture improves the structural properties of new concrete and enhances corrosion inhibition properties [56, 57]. The use of recycled concrete for new concrete by itself is a big leap towards better sustainability, and new research helps to overcome the current challenges of recycling waste concrete. The synergic effect of capturing air pollutants and using recycled concrete as a corrosion inhibitor can transform the construction industry, address air pollution, and reduce climate change. In summary, transformative methods for reducing concrete waste and air pollution can be the sustainable way forward.

Policy Recommendation

As all main air pollutants have an impact on the climate, air pollution and climate change are inextricably linked. Improving our air quality will benefit health, economic development, and the environment, as well as help mitigate climate change. This report highlights the mounting issues of air pollution, particularly from the construction industry, and emphasis on upcoming innovative methods to transform the construction industry and address climate change. Three policy implications are especially significant.

1. To foster sustainable innovation, policymakers must bring together industries and academia. Industries have the ability to scale up innovative intellectual discoveries on a large scale. As a result, codesigning policies across various areas would allow for dynamic synergies that would lead to sustainable waste management and reduce air pollution impact.

2. Implementing concrete recycling and air quality control measures for low-income countries should take into account the existing practices and high costs of some of the technologies utilized in developed countries. Decision making of which measures should be implemented must be based on rigorous economic and environmental analysis. Sharing of expertise from developed countries may be required to implement recycling and air quality control measures without impeding development.

3. Developed and developing countries must collaborate on such issues as sustainable construction and waste management. Through participation, collaboration, and regulation-based oversight, the industries must innovate and enable technological advancement that is economically affordable and environmentally sustainable for wider adoption.

References

[1] *Air pollution*. 2/21/2022]; Available from: https://www.who.int/health-topics/air-pollution#tab=tab_1.

[2] *Air pollution data portal*. 02/21/2022]; Available from: https://www.who.int/data/gho/data/themes/air-pollution.

[3] Al Smadi, B.M., K.K. Al-Zboon, and K.M. Shatnawi, *Assessment of air pollutants emissions from a cement plant: A case study in Jordan.* Jordan Journal of Civil Engineering, 2009. **3**(3).

[4] Abu-Allaban, M. and H. Abu-Qudais, *Impact assessment of ambient air quality by cement industry: A case study in Jordan.* Aerosol and Air Quality Resarch, 2011. **11**(7): p. 802-810.

[5] Mahasenan, N., S. Smith, and K. Humphreys, *The cement industry and global climate change: Current and potential future cement industry CO_2 emissions.* Greenhouse Gas Control Technologies, Vols I and Ii, Proceedings, 2003: p. 995-1000.

[6] Gartner, E., *Industrially interesting approaches to "low-CO_2" cements.* Cement and Concrete research, 2004. **34**(9): p. 1489-1498.

[7] Maddalena, R., J.J. Roberts, and A. Hamilton, *Can Portland cement be replaced by low-carbon alternative materials? A study on the thermal properties and carbon emissions of innovative cements.* Journal of Cleaner Production, 2018. **186**: p. 933-942.

[8] Worrell, E., et al., *Carbon dioxide emissions from the global cement industry.* Annual review of energy and the environment, 2001. **26**(1): p. 303-329.

[9] Chen, C., et al., *Environmental impact of cement production: detail of the different processes and cement plant variability evaluation.* Journal of Cleaner Production, 2010. **18**(5): p. 478-485.

[10] Nielsen, A.R., et al., *High-Temperature Release of SO_2 from Calcined Cement Raw Materials.* Energy & Fuels, 2011. **25**(7): p. 2917-2926.

[11] Hendriks, C.A., et al. *Emission reduction of greenhouse gases from the cement industry*. in *Proceedings of the fourth international conference on greenhouse gas control technologies*. 1998.

[12] Rall, D.P., *Review of the health effects of sulfur oxides.* Environ Health Perspect, 1974. **8**: p. 97-121.

[13] Spengler, J.D., et al., *Sulfur-Dioxide and Nitrogen-Dioxide Levels inside and Outside Homes and the Implications on Health-Effects Research.* Environmental Science & Technology, 1979. **13**(10): p. 1276-1280.

[14] Ware, J.H., et al., *Effects of Ambient Sulfur-Oxides and Suspended Particles on Respiratory Health of Preadolescent Children.* American Review of Respiratory Disease, 1986. **133**(5): p. 834-842.

[15] Lippmann, M., *Health-Effects of Ozone - a Critical-Review.* Japca-the Journal of the Air & Waste Management Association, 1989. **39**(5): p. 672-695.

[16] Ashby, M., *Materials and the Environment Eco-informed Material Choice*. 1 ed. 2009.

[17] Narayanan, N. and K. Ramamurthy, *Structure and properties of aerated concrete: a review.* Cement & Concrete Composites, 2000. **22**(5): p. 321-329.

[18] Redling, A. *Construction debris volume to surge in coming years*. 2018 [cited 2022 Jan 20]; Available from: https://www.cdrecycler.com/article/global-volume-construction-demolition-waste/.

[19] *Construction & Demolition Waste Market Report 2021: Opportunity in Innovations for Sorting and Recycling Technologies for Efficient Treatment of Construction & Demolition Waste*. 2021 [cited 2022 Jan 20]; Available from: https://www.researchandmarkets.com/r/3z2kd8.

[20] Shayan, A. and A. Xu, *Performance and properties of structural concrete made with recycled concrete aggregate.* Materials Journal, 2003. **100**(5): p. 371-380.

[21] Kim, G. and T. Kim, *Development of recycling technology from waste aggregate and dust from waste concrete.* Journal of ceramic processing research, 2007. **8**(1): p. 82.

[22] Tam, V.W., *Economic comparison of concrete recycling: A case study approach.* Resources, conservation and recycling, 2008. **52**(5): p. 821-828.

[23] *Construction and Demolition Debris Generation in the United States*. 2015: U.S. Environmental Protection Agency (EPA).

[24] Gull, I., *Testing of strength of recycled waste concrete and its applicability.* Journal of construction engineering and management, 2011. **137**(1): p. 1-5.

[25] Oikonomou, N.D., *Recycled concrete aggregates.* Cement and concrete composites, 2005. **27**(2): p. 315-318.

[26] Falcone Miller, S. and B.G. Miller, *7 - Advanced flue gas cleaning systems for sulfur oxides (SOx), nitrogen oxides (NOx) and mercury emissions control in power plants*, in *Advanced Power Plant Materials, Design and Technology*, D. Roddy, Editor. 2010, Woodhead Publishing. p. 187-216.

[27] Miller, B., *5 - Nitrogen oxides formation and control*, in *Fossil Fuel Emissions Control Technologies*, B. Miller, Editor. 2015, Butterworth-Heinemann. p. 243-280.

[28] Poon, C.S. and E. Cheung, *NO removal efficiency of photocatalytic paving blocks prepared with recycled materials.* Construction and Building Materials, 2007. **21**(8): p. 1746-1753.

[29] Seo, D. and T.S. Yun, *NOx removal rate of photocatalytic cementitious materials with TiO_2 in wet condition.* Building and Environment, 2017. **112**: p. 233-240.

[30] Guo, M.-Z., et al., *Pathways of conversion of nitrogen oxides by nano TiO_2 incorporated in cement-based*

materials. Building and Environment, 2018. **144**: p. 412-418.

[31] Pérez-Nicolás, M., et al., *Atmospheric NOx removal: Study of cement mortars with iron- and vanadium-doped* TiO_2 *as visible light–sensitive photocatalysts.* Construction and Building Materials, 2017. **149**: p. 257-271.

[32] Jin, Q., et al., *Quantification of NOx uptake in plain and* TiO_2*-doped cementitious materials.* Cement and Concrete Research, 2019. **122**: p. 251-256.

[33] Hüsken, G., M. Hunger, and H. Brouwers, *Experimental study of photocatalytic concrete products for air purification.* Building and environment, 2009. **44**(12): p. 2463-2474.

[34] Shen, S., et al., *Pervious concrete with titanium dioxide as a photocatalyst compound for a greener urban road environment.* Construction and Building Materials, 2012. **35**: p. 874-883.

[35] Folli, A., et al., TiO_2 *photocatalysis in cementitious systems: Insights into self-cleaning and depollution chemistry.* Cement and Concrete Research, 2012. **42**(3): p. 539-548.

[36] Dylla, H., et al., *Laboratory investigation of the effect of mixed nitrogen dioxide and nitrogen oxide gases on titanium dioxide photocatalytic efficiency in concrete pavements.* Journal of Materials in civil engineering, 2011. **23**(7): p. 1087-1093.

[37] Chen, M. and J.-W. Chu, *NOx photocatalytic degradation on active concrete road surface—from experiment to real-scale application.* Journal of Cleaner Production, 2011. **19**(11): p. 1266-1272.

[38] Ballari, M. and H. Brouwers, *Full scale demonstration of air-purifying pavement.* Journal of hazardous materials, 2013. **254**: p. 406-414.

[39] Senff, L., et al., *Formulation of mortars with nano-*SiO_2 *and nano-*TiO_2 *for degradation of pollutants in buildings.* Composites Part B: Engineering, 2013. **44**(1): p. 40-47.

[40] Lucas, S., V. Ferreira, and J.B. De Aguiar, *Incorporation of titanium dioxide nanoparticles in mortars—Influence of microstructure in the hardened state properties and photocatalytic activity.* Cement and Concrete Research, 2013. **43**: p. 112-120.

[41] Matějka, V., et al., *Metakaolinite/*TiO_2 *composite: Photoactive admixture for building materials based on Portland cement binder.* Construction and Building Materials, 2012. **35**: p. 38-44.

[42] Chen, J., S.-c. Kou, and C.-s. Poon, *Photocatalytic cement-based materials: Comparison of nitrogen oxides and toluene removal potentials and evaluation of self-cleaning performance.* Building and Environment, 2011. **46**(9): p. 1827-1833.

[43] Hunger, M., G. Hüsken, and J. Brouwers, *Photocatalysis applied to concrete products.* ZKG international, 2008. **61**(10): p. 76-84.

[44] Kolarik, J. and J. Toftum, *The impact of a photocatalytic paint on indoor air pollutants: sensory assessments.* Building and environment, 2012. **57**: p. 396-402.

[45] de Melo, J.V.S. and G. Trichês, *Evaluation of the influence of environmental conditions on the efficiency of photocatalytic coatings in the degradation of nitrogen oxides (NOx).* Building and Environment, 2012. **49**: p. 117-123.

[46] Yang, L., et al., *Photocatalytic concrete for NOx abatement: Supported* TiO_2 *efficiencies and impacts.* Cement and Concrete Research, 2019. **116**: p. 57-64.

[47] Macphee, D.E. and A. Folli, *Photocatalytic concretes — The interface between photocatalysis and cement chemistry.* Cement and Concrete Research, 2016. **85**: p. 48-54.

[48] Krou, N.J., et al., *Mechanisms of NOx entrapment into hydrated cement paste containing activated carbon — Influences of the temperature and carbonation.* Cement and Concrete Research, 2013. **53**: p. 51-58.