CHAPTER 5: Urban Form, Structure and Air Quality

General Overview

The objectives of the urban infrastructure component of this Inquiry were to identify planning and design strategies for improving Australian urban environments and to attempt to quantify the reduction in pollutant emissions (and energy use) and consequent improvement in air quality achievable via different strategies.

The pattern of urban development that characterises all cities in Australia depends upon fossil fuels as the principal source of energy. They have evolved particular land use and transportation patterns which are far from optimum in terms of economic efficiency, social equity and environmental performance (Newman *et al* 1996). As Colley (1997) has recently argued:

'...the new environmental constraints—there are many—do not relate to the exhaustion of finite resources, but to the capacity of our health and that of the surrounding ecological systems to cope with the way we are producing and using energy'.

In the context of the present report, our concern is a dual one, minimise energy consumption and thus minimise atmospheric pollution. The desirable path for future metropolitan development is one which seeks to minimise resource inputs such as energy and reduce waste outputs such as air pollution and greenhouse gases.

For urban planning, this means greater consideration being given to issues such as the 'shape' of urban development, better integration of transport and land use, minimising the amount of travel required and encouraging higher levels of self-containment. Several alternative urban forms are examined in relation to their capacity to deliver better energy consumption and air quality performance outcomes.

City planners should not be diverted from action by those who suggest that the form and structure of cities is difficult to modify. Rapid change in urban structure has been demonstrated in the space of the last 10-15 years. This shows that strategic urban policies and infrastructure investments could lead, in a finite time, to a re-shaping of cities to a more positive and sustainable form.

Integrated land use-transport-emission-airshed modelling has been undertaken specifically by CSIRO for this Inquiry. It explores the joint effects of changing residential, workplace and transport structures on energy consumption and urban air quality to the year 2011.

The conclusion is that urban form *does* matter. And not just for urban air quality. In relation to indicators such as energy consumption, self-containment of sub-urban regions and vehicle kilometres travelled, the conclusions are that to maintain a 'business as usual' model (relatively low density, dispersed city form) of urban development will create, and continue to create, sub-optimal living and working environments. All three tiers of government must become more pro-active in re-shaping cities.

In addition to the raft of individual strategies capable of being focused around housing, offices, factories and transportable individual building blocks of urban systems, higher order improvements to urban environmental quality are possible via integrated approaches to the planning, design, management and operation of built environments. Two strategies which offer step-function benefits are the building fingerprint and integrated land use-transport-environment planning.

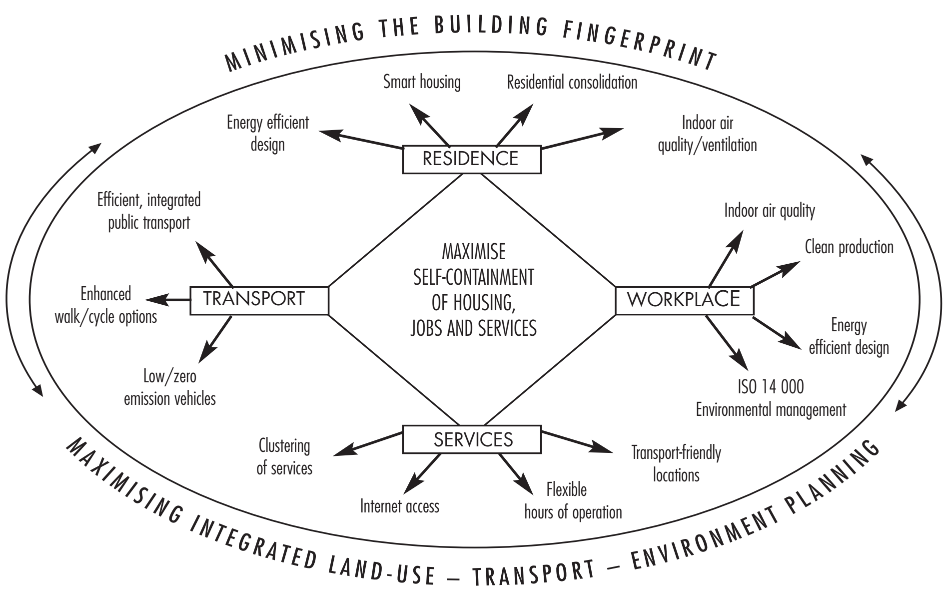

Figure 43: An integrated approach to environmental design and planning of cities

The misconception that cities change slowly arises from the fact that concepts of urban form and urban structure tend to be blurred or used interchangeably. By urban form we mean the characteristic morphology of settlement represented by the key physical infrastructures of a city; road and rail networks, ports and airports, telecommunications and hydraulic networks. These are durable and relatively stable infrastructures that tend to retain their form for many decades, although parts may undergo more rapid change at times.

By urban structure we mean the manner in which residential and industrial land uses are distributed throughout a city. These have been the subject of analysis and mapping over a considerable period of time (Johnston, 1971; Murphy, 1974).

Urban structures are highly dynamic and can change radically in the space of a decade or so. Urban form is less dynamic, but can nonetheless be fast-changing, as regions like south east Queensland and most Asian cities can attest.

Urban form and structure together define an urban system, whose spatial configuration may be found to align itself variously with one of several 'archetypal' patterns (Gibson, 1977; Pressman, 1985; Minnery, 1992). These are illustrated in Figure 44 and may be summarised as follows:

- *dispersed city* — outward expansion at relatively low densities, random infill and remaining dominated by a central city as the key economic node. At present Australia's large cities are more closely aligned to this urban form than to any of those below;
- *compact city* — increased population and density of inner group of suburbs;
- *multi-node city* — increased population, housing densities and employment in selected nodes across the city; increased investment in orbital rail links or freeways linking the nodes;
- *corridor city* — a focusing of growth along linear corridors emanating from the CBD and supported by upgraded public transit infrastructure;
- *fringe city* — where additional growth is accommodated predominantly on the fringe of the city; and
- *ultra city* — where additional growth is accommodated primarily in provincial cities within 100 km of the principal (capital) city and linked by high speed rail transport.

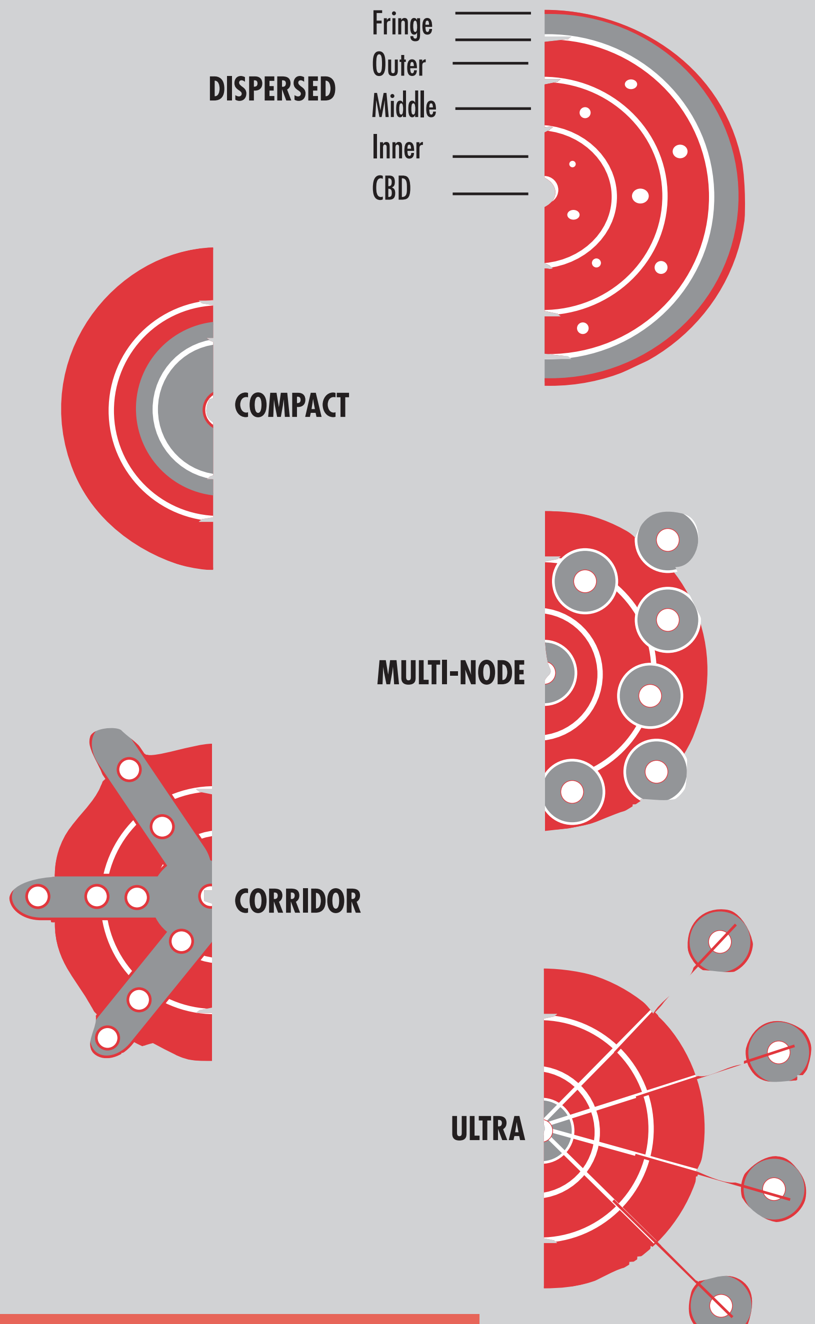

Figure 44: Archetypal city forms

Each scenario represents a relatively extreme possibility, deliberately selected to explore for shifts in air quality performance, as the archetypal city is alternatively re-shaped along the lines outlined above. Sydney, Melbourne, Brisbane, Adelaide and Perth show similar metropolitan characteristics in terms of industrial and residential dispersal and trip distances. A prototypical Australian city (based on Melbourne's characteristics, Table 16) was therefore modelled to the year 2011 via a set of scenarios aligned to the archetypal urban systems. Time and resources available to the Inquiry did not permit calibration and application of the urban model to the other cities.

The Effects of Urban Form on Air Quality: Melbourne as a Case Study

The results of the modelling proved dramatic in relation to impact on urban air quality. When worst case scenarios relating to summer photochemical smog and winter particle concentrations were examined for Melbourne in 2011, it was found that the air quality impact (for smog) can vary from a 53% *improvement* under a corridor scenario to a 73% *deterioration* in pollution exposure by resident populations if development occurred on a business as usual course, Figure 19.

Where new development is primarily concentrated at nodes, the air quality enhancements are also significant compared to the base case. For business as usual development, the result is a 71% increase in the population exposed to smog at levels above the proposed Air NEPM Standards.

For an adverse winter day with particle build up in the atmosphere, performance varied from a 14% improvement for a Corridor City to 61% for business as usual. The Compact City, though the most energy efficient, produces the highest personal exposure to particulates due to its more concentrated population.

Modelling Community Response

The urban infrastructure models applied by the CSIRO allow a detailed set of outcomes to be determined for any given scenario. For example what if we forecast a high pollution summer day in Melbourne and a plea was made to use public transport on that day? Would the response and the consequences be worthwhile?

Suppose the response (within the bounds of possibility for Melbourne) were to be four per cent of commuters take the day off; of the remaining trips 16% fewer car trips are made and there is a 45% higher patronage of public transport

Table 16: Melbourne as a prototype. Data and assumptions 1991-2011

Data

Data on travel origins, destinations and modes were available for 1991 and earlier census years from the Journey to Work study by Gipps *et al.*(1997) for five capitals. More recent census data is not yet available. Data on emissions and distributions of air pollutants were obtained for Melbourne for 1990 from the Victorian EPA.

Emission rates

Emission factors for five pollutants (CO, NOx, CO, SO_2 and PM_{10}) were obtained for the Port Phillip Control Region (PPCR) (Carnovale *et al.,* 1991) for four types of roads under free-flow and congested conditions. The emission factors used in the future scenarios incorporate anticipated advances in fuel efficiency and increased emissions technology uptake for motor vehicles.

Link source CO_2 emissions were based solely on the consumption of petrol by passenger or light commercial vehicles.

New land use activities

- Industrial zones. The same industrial (non-residential) zones are assumed in each scenario, with growth in areas given over to industry (20%) located on land zoned industrial at the periphery, in the corridor and with access to ring and radial freeways.
- Residential development**.** A 16% increase is assumed over the period 1991-2011.
- Service industries**.** A 47% increase over the period 1991-2001 is assumed.
- Manufacturing industries**.** For manufacturing, a 5% level of job growth is assumed, but lower worker densities, given 20% greater industrial area.
- Road and rail network**.** A simplified road and rail network was employed which represented the major streets, freeways, highways and arterials in the Melbourne region.

CSIRO land use and transport models

Over the last 20 years, the CSIRO Division of Building Construction and Engineering has developed a suite of land use and transport models and advanced spatial optimisation tools for a range of infrastructures, Brotchie *et al.* (1980), Gibert and Maheepala (1995). TOPAZ 2000 is a considerably enhanced version of the earlier TOPAZ (Technique for Optimal Placement of Activities in Zones) and was used in this study.

(mostly train), effectively a change from the present 80:20 private:public transport split to 70:30. Then for the forecast day the prediction is for a 28% *lessening* in pollution exposure for Melbourne residents, Figure 45.

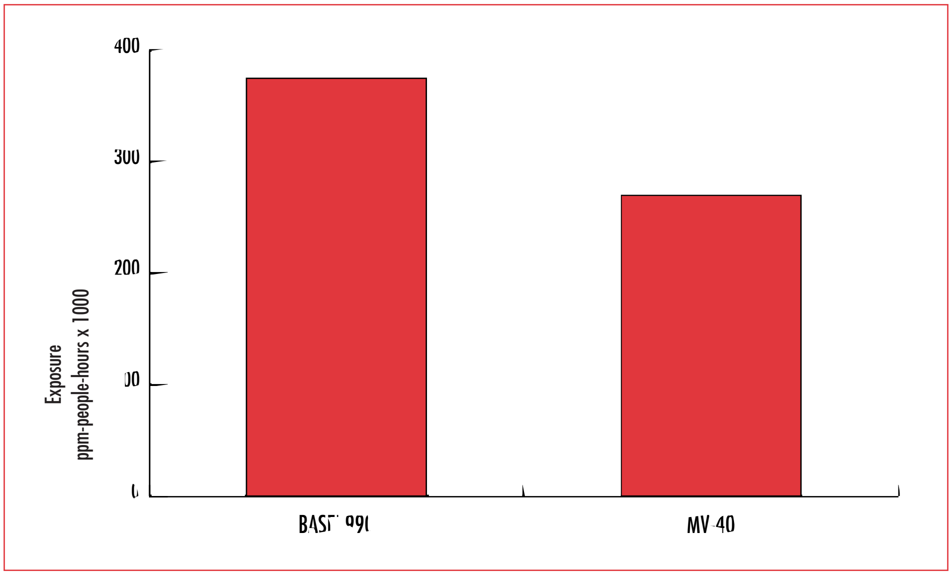

Figure 45: Forecast public response to a high pollution summer day in Melbourne

Broad Outcomes from Changes to Urban Form

Base case

Emission estimates were obtained for the 1991 base case, Table 17, using TOPAZ 2000. Link emissions include those from freeways and major road systems. Link sources account for the overwhelming proportion of NOx and CO emissions and about half of VOC and PM_{10}. Area sources contribute significantly to VOC and PM_{10} emissions.

Outcomes from Land Use-Transport-Environment Models to 2011

Levels of emissions for Melbourne in the 1991 base case and six scenarios for the year 2011 are listed in Table 18. Percentage changes in emissions between the 2011 scenarios and 1991 base are provided in Table 19.

Table 17: Emissions (000s kilograms per day) for the 1991 base case

Emission Source	VOC	NOx	CO	SO_2	PM_{10}
Link	244.2	187.0	1930.9	5.2	11.2
	(53.4%)	(79.0%)	(92.0%)	(12.1%)	(45.0%)
Area	126.5	11.6	132.9	1.3	6.4
	(27.7%)	(4.9%)	(6.3%)	(3.0%)	(25.7%)
Point	86.1	38.1	35.9	36.5	7.3
	(18.8%)	(16.1%)	(1.7%)	(85.9%)	(29.3%)
Total	456.8	236.7	2099.7	43.0	24.9

Key findings include:

- continuation of business as usual, Dispersed City, development results in continued growth in emission levels across the board, but particularly for CO and CO_2 due primarily to growth in vehicle kilometres travelled;
- Compact City form is associated with the largest relative reductions in level of emissions, due to significantly lower VKT; and
- Corridor City form, a relatively accessible extrapolation from the present, performs creditably.

On the basis of this evidence, urban development which departs from the current dispersed trend to one of a more compact nature has significant benefits from the point of view of lower levels of daily emissions across the full set of pollutant types addressed in this study. A comparative perspective for 2011 is provided in Table 20 wherein the Dispersed City is contrasted against all other configurations with similar conclusions.

Urban Form and Energy Consumption

As might be expected from the section above, the Compact City emerges as the most fuel efficient of all urban forms (Figure 46) with 43 per cent less fuel consumption than a dispersed form. In the Corridor City, infrastructure is

Table 18: Total emissions (tonnes per day) for the 1991 base case and six future city scenarios (2011)

Scenario	CO	VOC	NOx	SO_2	PM_{10}	Link CO_2
Base 1991*	2099.7	456.8	236.7	43.0	24.9	20616.6
Dispersed**	2569.9	531.1	279.5	44.3	28.2.	26638.3
Compact	1376.6	366.6	189.3	42.1	24.7	15136.7
Multi-node	1751.7	409.0	230.1	43.3	27.6	20858.3
Corridor	1694.0	404.0	231.4	43.5	28.2	22499.8
Ultra	1767.7	412.4	237.1	43.7	28.5	22374.5
Fringe	1842.1	420.7	239.0	43.6	28.3	21119.0

*Technological changes are predicted to substantially reduce emissions per VKT between 1991 and 2011.

** Business as usual.

Table 19: Percentage change in emissions in 2011 compared to 1991 base case

Scenario	CO	VOC	NOx	SO_2	PM_{10}	Link CO_2
Dispersed	16.3	18.1	22.4	3.0	13.3	29.2
Compact	-19.7	-20.0	-34.4	-2.1	-0.7	-26.6
Multi-node	-10.5	-2.8	-16.6	0.7	10.8	1.2
Corridor	-11.6	-2.2	-19.3	1.2	13.3	9.1
Ultra	-9.7	0.2	-15.8	1.5	14.6	8.5
Fringe	-7.9	1.0	-12.3	1.3	13.6	2.4

Table 20: Percentage reduction in total emissions as compared to business as usual scenario for 2011

Scenario	Link CO_2	VOC	NOx	CO	SO_2	PM_{10}
Compact	31.0	32.3	46.4	5.0	12.3	43.2
Multi-node	23.0	17.7	31.8	2.3	2.1	21.7
Corridor	23.9	17.2	34.1	1.8	0.0	15.5
Ultra	22.4	15.2	31.2	1.5	-1.2	16.0
Fringe	20.8	14.5	28.3	1.7	-0.3	20.7

primarily radial in nature. Consequently higher levels of daily travel were generated than in other scenarios (ie limited prospects for cross town trips). The addition of a higher order ring or orbital transport network to Corridor City infrastructure, moving it more to a multi-node structure, could be expected to generate positive benefits in travel time and energy consumption outcomes.

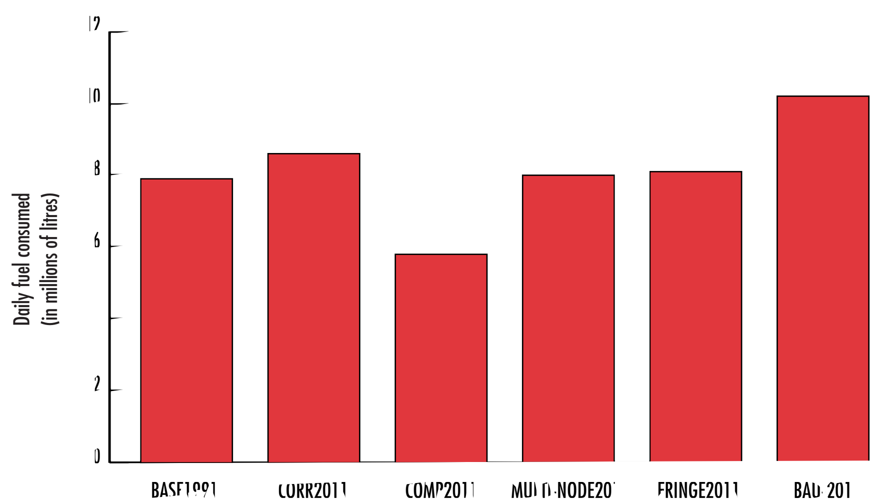

Figure 46: Effect of urban form on fuel use: projections for different city forms in 2011

LAND USE — TRANSPORT — ENVIRONMENT PLANNING: THE ROLE OF GOVERNMENT

Governments have a prime responsibility to shape the development and re-development of their cities according to principles that will provide greatest opportunity for their long term economic, environmental and social sustainability. It is now possible for local or State government planning agencies to evaluate a range of possible development futures - as has been done in this report - and use the outcomes as a basis for guiding major infrastructure investment decisions and broad development strategies for a city.

It is this type of strategic planning and evaluation which is notably absent at State government level as attempts are made to chart the future infrastructure investments required for major metropolitan areas into the 21st century. By way of contrast, in the United States the Federal Clean Air Act requires a close linking of urban transport and development with a set of goals, including air quality, in order for cities to qualify for Federal funding. Integrated land use-transport-environment models represent the only means by which impacts of proposed urban development can be evaluated across the spectrum of dimensions relevant to the key goals of economic efficiency, social equity and environmental sustainability.

The Building Fingerprint: A Strategy for Government and Private Enterprise

The 'ecological footprint' (Rees, 1992) has emerged as a powerful macro-level concept which attempts to better define the spatial envelope of impacts exerted by cities on the wider environment (Newman *et al*, 1996). At micro-level, the concept of *'building fingerprint'* has been advanced by Baldwin and Yates (1996) as a means of evaluating all aspects of industrial or commercial based activity for environmental impacts. The objective is to minimise energy consumption and emissions generation associated with the *construction*, *operation*, *maintenance* and *utilisation* of individual buildings.

In the context of this report, the building fingerprint concept has much to commend it as a strategy for government and private enterprise:

- minimising embodied energy of materials used in construction and substitute re-fit through judicious selection of low energy materials;
- minimising operating energy by adopting a life cycle approach in design whereby durability, serviceability and fitness for purpose are optimised and energy audit procedures become routine elements of building operations;

- minimising the person kilometres travelled to and from work by employees as a result of enterprises locating their offices within overlapping labour markets and housing market areas, thereby increasing the self-containment of sub-urban areas within cities; and

- minimising the vehicle kilometres travelled by an enterprise's transport fleet in servicing the needs of its customer/client base (i.e., optimising its location within a particular trade market catchment area).

Incentives must be sought which are capable of encouraging enterprises to minimise their building fingerprints. These are likely to be embraced more readily by building owners who are incorporating environmental as well as economic considerations in their procurement policies.

As the nation's largest building owners, governments at all levels are well placed to offer leadership in this particular strategy.

Whole-of-life Design for Optimal Energy Use and Minimum Emissions

The greatest impediments to energy efficiency in Australia have been the high cost of capital and relatively low cost of end-use energy. It is not surprising to find that much of the energy use in buildings can be traced to the installation of low capital cost, high running cost services and that little attention is focused on the *whole-of-life costs* which are associated with owning and operating the building. A further deterrent to the adoption of energy efficiency measures is that the owner-builder of a constructed facility (house, office building, factory) is frequently not the occupier-operator and therefore does not have responsibility for long term energy costs.

Operating energy and thermal design

Australian buildings consume about 18 percent of end-use energy. This represents annual expenditure of about $6.3 billion. Because buildings last a long time, the costs of poor design will be felt for decades. Complex interactions between the building, its occupants and its services mean that simple design rules used in the past are no longer adequate.

The design base for the National Home Energy Rating Scheme (NatHERS), allows the thermal performance evaluation of a building prior to its construction. For a house with a 5 star energy rating, the annual operating energy is less than 4% of the embodied energy. For a life span in the order of 50-60 years, embodied energy comes to represent approximately one-third of its life cycle energy outlay. For houses with a poor star rating (0 or 1), the main focus should be in reducing operating energy because it is likely that within 10 years of construction more operating energy is used than was taken to build it. There is clear evidence that star ratings can be raised quickly to a 3-star level with only marginal changes to embodied energy, particularly through basic insulation.

Building re-use

Assigning higher priority to re-use or re-furbishing buildings can also mean a retention of up to 60 per cent of the embodied energy that went into the original structure. Design for re-use needs to become a higher priority within the building and construction industry as it has become within the automotive industry.